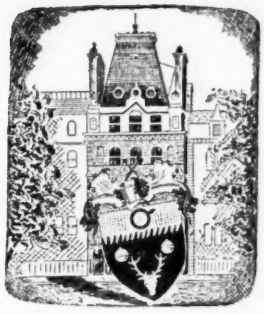
PROCEEDINGS OF THE INSTITUTE



Reports of Council · Meetings · Notices

ANNUAL GENERAL MEETING, 1955

The EIGHTY-SIXTH ANNUAL GENERAL MEETING OF THE IRON AND STEEL INSTITUTE was held on Wednesday and Thursday, 27th and 28th April, 1955, at the Offices of the Institute, 4 Grosvenor Gardens, London, S.W.1. The Honourable R. G. LYTTELTON, the Retiring President, was in the Chair at the beginning of the Meeting, his place being taken later by Sir CHARLES BRUCE-GARDNER, Bt., the new President.

Sessions were held at 9.45 A.M. and 2.30 P.M. on the Wednesday and at 10.30 A.M. and 2.30 P.M. on the Thursday. On the Wednesday evening, a Dinner for Members was held at Grosvenor House, Park Lane.

The minutes of the previous meeting were taken as read, and were confirmed and signed.

The **President** (The Hon. R. G. Lyttelton) began by welcoming the Members and visitors to the meeting, and in particular those who had come from Sweden, Finland, and The Netherlands. On behalf of the Council, he also welcomed representatives from other countries, including Australia, Belgium, Canada, France, Germany, and the U.S.A.

PRESENTATION OF REPORT OF COUNCIL AND STATEMENT OF ACCOUNTS FOR 1954

The **President** then presented the Report of the Council and the Statement of Accounts for 1954, which were published in the April issue of the *Journal*. He spoke first of the nomination of Mr. Evert Wijkander and Bergrådet Berndt Grönblom to be Honorary Vice-Presidents and the election of Mr. Ernst Gustaf (Gösta) Frisell as an Honorary Member of the Institute. This had been done as an expression of appreciation of all that had been done for the Institute during the meeting in Sweden and the subsequent visit to Finland.

A number of other meetings had also been held during the year, including two of exceptional interest: the Joint Meeting with the French and British Forgemasters, and the Second Symposium on Powder Metallurgy. The meetings of the Engineers Group were also mentioned, including those held in Newcastle and Buxton, and the President paid tribute to the work of the Chairmen of the Group—Mr. W. F. Cartwright, Mr. C. H. T. Williams, and the present Chairman, Mr. W. M. Larke.

In the summer of 1943, the Council arranged for a comprehensive Report on Metallurgical Education to be prepared, and this was published in the *Journal* in February, 1944. After an interval of over ten years, it was interesting to note that many recent developments were foreshadowed in the Report, and that most of the recommendations made in it had been carried out.

The Joint Committee on Metallurgical Education, which was set up in 1944 as a direct result of this Report, had been disbanded, and the participating Institutions were now represented on the Education Committee of the Institution of Metallurgists. It had also been agreed that the administration of the Joint Committee for National Certificates in Metallurgy, for which the Institute had been responsible since the Committee was formed in 1945, should be entrusted to the Institution of Metallurgists from the beginning of 1955.

The **Honorary Treasurer** (Mr. W. Barr), who seconded the motion, then presented the Statement of Accounts. He said that some changes had been made in the form in which the accounts were presented in order to make them easier to read: the Publications Account was no longer shown separately, and a Suspense Account for Special Reports had been opened, any balance from it being carried over to the Balance Sheet. For 1954 the credit balance for the Special Reports was about £5, but it was interesting to note that, had an account been kept on similar lines over the past six years, there would have been a credit balance of about £2000.

The income for the year showed a net surplus of £3109, which, together with a surplus of £221 from the Swedish visit, made a total available surplus of £3330.

The gross income was £78,354, an increase of £4500

over the previous year. This was due largely to an increase in publication activities, which produced an income of nearly £51,000, an increase of £5000. Every attempt should be made to increase the Membership of the Institute so that a larger proportion of the income might come from Members' subscriptions.

Another change in the Accounts was that a House Fund Cost of Lease Account was shown on the Balance Sheet. The amount written off the lease during the year was £1410 as compared with £1108 last year.

The Reserve for Repairs and Decorations had been increased from £1000 to £3000 in view of the cost that had been incurred since the beginning of the current year in redecorating the building internally and externally.

The motion was carried unanimously.

PRESENTATIONS

The Bessemer Gold Medal for 1955 was awarded to Professor John Chipman, Head of the Department of Metallurgy, Massachusetts Institute of Technology, in recognition of his distinguished contributions to the knowledge of the physical chemistry of steelmaking.

The **President** stated that as Professor Chipman was unable to be present, the Medal would be presented to him on 1st June, at the Opening Plenary Session in London of the Joint Metallurgical Societies Meeting.

The Sir Robert Hadfield Medal for 1955 was awarded to Mr. Tor Fjalar Holmberg, of Oy Vuoksenniska A.B., in recognition of his meritorious service in improving the technique of the production of iron and steel at the Imatra Works, Finland.

The **President** stated that as Mr. Holmberg was unable to be present, the Medal would be presented to him at the Scunthorpe Meeting in the autumn.

The **President** then made the following presentations:

An Andrew Carnegie Silver Medal for 1954 to Dr. B. Cina, of the Brown-Firth Research Laboratories, in respect of research at Sheffield University and a paper on "The Effect of Cold Work on the Gamma → Alpha Transformation in some Fe–Ni–Cr Alloys," published in the *Journal* for August, 1954.

Three Williams Prizes for 1954, of £100 each, to Mr. W. Jackson, of the Appleby-Frodingham Steel Co., for his paper on "Use of Coke-Oven Gas and Pitch-Creosote Firing on Tilting Furnaces," published in the *Journal* for December, 1954; to Mr. R. McDonald, of Colvilles Ltd., for his paper on "Steelworks Waste Heat Boiler Practice," published in the *Journal* for January, 1954; and to Mr. A. Stirling, of Stewarts and Lloyds Ltd., for his paper on "The Pelletizing of Northampton Sand Ironstones by Vacuum Extrusion," published in the *Journal* for May, 1954.

AFFILIATED LOCAL SOCIETIES

The **President** announced that since the beginning of the year the Sheffield Metallurgical Association had become affiliated to the Institute. By agreement with the Sheffield Society of Engineers and Metallurgists, an exception had been made to the rule by which normally only one Society in each district was affiliated.

AWARD OF HONORARY MEMBERSHIP TO SIR WILLIAM LARKE, K.B.E.

The **President** then announced that Sir William Larke, K.B.E., had been nominated to be an Honorary Member of the Institute. Honorary Membership was one of the highest honours that could be bestowed on a Member. This nomination had been made on the preceding day, which was the eightieth anniversary of Sir William's birthday, and was in recognition of his long, distinguished, and valiant service to the iron and steel industry. His achievements had been especially great in furthering co-operation in the industry and in raising its prestige both at home and abroad.

Sir William Larke, in reply, expressed his deep appreciation of the honour conferred on him.

ANNOUNCEMENTS

The **Secretary** (Mr. K. Headlam-Morley) made the following announcements:

Changes on the Council since the last General Meeting in November, 1954:

Honorary Members of Council during their periods of office:

Dr. Maurice Cook, F.I.M., President of The Institute of Metals, in place of Dr. S. F. Dorey, C.B.E., F.R.S.

Mr. T. H. Arnold, President of The Sheffield Metallurgical Association, in place of Mr. F. H. Saniter (Mr. Saniter remains on the Council as a Member).

Retiring Members of Council—In accordance with Bye-law 10, the names of the following Vice-Presidents and Members of Council had been announced at the Autumn Meeting, 1954, as being due to retire at the present Annual Meeting:

Vice-Presidents: Mr. G. H. Latham, Mr. J. Sinclair Kerr, and Dr. H. H. Burton.

Members of Council: Dr. J. W. Jenkin, Mr. W. F. Cartwright, Mr. F. H. Saniter, Mr. T. Jolly, and Mr. R. A. Hacking.

No other Members having been nominated up to one month previous to the present meeting, the retiring Vice-Presidents and Members of Council were presented for re-election and declared by the President to be duly re-elected.

Andrew Carnegie Scholarship: The following award had been made since the last General Meeting:

£150 to Mr. A. S. Appleton (Liverpool University) to assist research on "The Kinetics of Graphitization in High-Carbon Fe–C and Fe–Co–C Alloys, together with Subsidiary Diffusion Experiments on Fe–C–Si and the above Alloys."

Future Meetings—*The Joint Metallurgical Societies Meeting in Europe,* 1955, would be held on 1st–18th June. The British Section, which was joint with The Institute of Metals and the American Institute of Mining and Metallurgical Engineers and American Society for Metals, would take place on 1st–7th June. This would be followed by meetings in Germany, Liège, and France.

A Special Meeting in Scunthorpe would be held, by invitation of the Lincolnshire Iron and Steel Institute, on 12th–14th October, 1955.

The Eighth Hatfield Memorial Lecture would be delivered by Dr. E. C. Bain at Sheffield on 17th October, 1955.

The Autumn General Meeting would be held in London on 16th and 17th November, 1955.

BALLOT FOR THE ELECTION OF MEMBERS

The scrutineers of the ballot, Mr. **E. Holland** (Manchester) and Dr. **S. A. Main** (London), reported that the following candidates had been duly elected:

Members

Ahmad, Zia Uddin (Pakistan); **Alleaume,** J. H. (France); **Ando,** Kohei (Japan); **Ashforth,** Hugh William (S. Rhodesia); **Atkin,** David John, B.Sc. (Chem. Eng.)

(Birmingham); **Bayliss,** Rex Norman (Halesowen); **Bee,** Kenneth William, L.I.M. (Rainham); **Bentley,** George Arthur (Birmingham); **Best,** Eric Roland (Birmingham); **Bose,** Kalyan, B.Sc. (West Germany); **Brittain,** Charles Peter, B.A., Grad.I.E.E. (Cambridge); **Bulford,** Frank Frederick, A.M.I.E.E. (London); **Burgess,** Alfred Joseph (Port Talbot); **Cameron,** Hugh (Sheffield); **Carpenter,** Joel C., B.Sc. (Met. Eng.) (U.S.A.); **Cavanagh,** Patrick Edgar, B.A.Sc. (Canada); **Challinor,** Henry Clive (Scunthorpe); **Chester,** John Standley (Leeds); **Comins,** Harold Ernest, A.I.M. (Lincoln); **Crawley,** Arthur William, L.I.M. (Burnley); **Da Costa,** Alfredo Nobre (Portugal); **de Lacalle,** Francisco (Spain); **Dent,** Albert Mervyn, A.C.G.I. (London); **Dodd,** Richard Arthur, M.Sc., Ph.D., F.R.I.C., A.I.M. (Canada); **Dowhaniuk,** William P., B.Sc. (Met. Eng.) (Canada); **Eccles,** John Gerald Turton, D.L., J.P. (Scunthorpe); **Elliott,** John F., Sc.D., B.Met.E. (U.S.A.); **Evans,** Denis Wilfred Morgan, B.Sc. (Ebbw Vale); **Francis,** A. V., A.M.I.Mech.E., A.M.I.E.E. (Dudley); **Gavioli,** Gaetano, Dott. (Italy); **Gould,** James C. (U.S.A.); **Green,** Reginald, B.Sc.(Eng.), A.C.G.I., Grad. I.E.E. (Rotherham); **Gunstone,** Charles Philip, B.A. (Hons.) (Corby); **Hay,** Donald Molson (London); **Hennessy,** Jerrold Anthony (London); **Heslop,** Gordon Burfield, M.Sc.(Eng.), A.I.M. (London); **Hirst,** T. J., B.Sc., A.I.M. (Port Talbot); **Hocepied,** Jean B. F. (Belgium); **Hodierne,** Francis Arthur, B.Sc., A.I.M. (Birmingham); **Hocke,** Hans (London); **Hower,** Edwin N., B.Sc. (Met. Eng.) (U.S.A.); **Johnson,** Walter E., M.E. (U.S.A.); **Kennedy,** Alfred James, B.Sc., Ph.D., A.M.I.E.E., F.Inst.P. (London); **Killingbeck,** William (Barrow-in-Furness); **LaBelle,** Robert J. B., B.A.Sc. (U.S.A.); **Lane,** David William Stennis Stuart, M.A. (London); **Lant,** William Henry (London); **Latty,** Clive Way, B.Sc. (Nuneaton); **Linder,** Rolf (Sweden); **Llewellyn,** David, F.I.M. (Wednesbury); **Luerssen,** Frank W., M.S. (Met. Eng.) (U.S.A.); **Lundgren,** Bengt (Sweden); **McBride,** David L., A.B., M.S., D.Sc. (U.S.A.); **McDonald,** Robert (Motherwell); **Meek,** John William, A.M.I.E.E. (Rugby); **Miller,** Oscar O., M.S., Ph.D. (U.S.A.); **Moore,** James H., B.Sc. (U.S.A.); **Moran,** Leslie Owen (Birmingham); **Myers,** William Henry (Middlesbrough); **Nathorst,** Helmer (Sweden); **Nayar,** Amar Prakash, B.Sc.(Met.) (India); **Nicholson,** George A., B.Sc., Ph.D., A.R.I.C. (Rotherham); **Okamoto,** Eiji (Japan); **Pagan,** Albert Victor, B.Sc. (Middlesbrough); **Pearce,** M. S., B.Sc. (Wolverhampton); **Plummer,** Harry (London); **Powell,** Alfred R., A.M., B.S., Ph.D. (U.S.A.); **Pratt,** Kenneth Graham (Shotton); **Rathbone,** Michael P., M.Eng., A.M.I.C.E., A.M.I.E.E. (Scunthorpe); **Ratti,** Dr.-Ing. Giuseppe (Italy); **Reid,** C. L. (Scunthorpe); **Reitsema,** R. (Holland); **Rendall,** Edward Holden Shuttleworth (Sheffield); **Rivkine,** James W. (London); **Rippon,** John Roy, B.Sc. (Sheffield); **Roehl,** Edward J., B.Chem. (U.S.A.); **Rosendahl,** Carl-Henrik Theodor (Sweden); **Rutherford,** Walter James Hunter (Australia); **Sankey,** James Charles (Dudley); **Sastry,** Bhamidipati Ganapathy, B.Sc.(Met.) (India); **Schwarzkopf,** Alex J., M.S. (Met. Eng.) (U.S.A.); **Seigle,** J. (France); **Sharma,** D. N. (India); **Smith,** Francis Harwood, A.M.I.E.E. (London); **Somers,** Alfred Christopher (Halesowen); **Somers,** Walter (Halesowen); **Southern,** George Arthur (Manchester); **Stanford,** Kenneth, B.Sc. (Met.) (London); **Travis,** Robert William, A.M.C.T., A.M.I.Mech.E., A.M.I.Prod.E. (Brentford); **Unterweiser,** Paul M., B.S. (Chem. Eng.) (U.S.A.); **Vaughan,** Colin (London); **Ver,** Tibor, Prof. Dr.techn. (Austria); **Warren,** Alfred John, B.Sc.(Eng.), Grad.I.E.E. (Spain); **Watanabe,** Seiichiro (Japan); **Watson,** James T., A.R.T.C., G.I. Mech.E. (Motherwell); **Wellensiek,** Gert, Dipl.Ing. (Germany); **Whitley,** Elfred, B.Sc., A.M.C.T., L.I.M. (Shotton); **Williams,** Milton F., jun., B.Eng., M.Sc. (U.S.A.); **Williams,** William Evan (Ebbw Vale); **Wittels,** William, Dipl.Ing., A.F.R.Ae.S. (London); **Wright,** John William (Cwmbran); **Wusatowski,** Zygmunt, D.Sc. (Poland); **Yates,** Brian Peel (Bradford).

Associate Members

Beevers, Christopher John (Sheffield); **Boler,** Robert (Sheffield); **Briggs,** Gordon (Middlesbrough); **Brunner,** Paul Anthony (Smethwick); **Cartwright,** Brian (Sheffield); **Cook,** Peter James (Sheffield); **Cotton,** W. D. V. (Swansea); **Crane,** Herbert Wilfred (Peterborough); **Cranidge,** John Curtis (Newark); **Davies,** Peter Wesley (Swansea); **Dewsnap,** Ronald Francis, A.Met. (Sheffield); **Evans,** John Ronald (Swansea); **Evans,** Peter Rees Vaughan, B.Sc.(Hons.) (Swansea); **Fido,** Alan Thomas (Derby); **Fox,** Michael Robert (Wolverhampton); **Gibson,** Donald (London); **Haile,** Ian (Sheffield); **Hudson,** Derek Anthony (London); **Hutchinson,** Robert Ian (Newcastle-on-Tyne); **Machin,** John Donald Ray (Newcastle-on-Tyne); **Mead,** Terrence Clive (Swansea); **Meadows,** Brian John, L.I.M. (Birmingham); **Niven,** Robert Timothy (Glasgow); **Pawelski,** Brian (Middlesbrough); **Richards,** Jeffrey Roy (Sheffield); **Roberts,** Elwyn (Sheffield); **Sands,** Raymond Leonard (Wednesbury); **Sellars,** Christopher Michael (Sheffield); **Sidebottom,** Barrie Armitage (Sheffield); **Simpson,** Roy (Bromsgrove); **Sunavala,** Pharokh Dhunjishaw, B.Sc. (Sheffield); **Wilson,** Eric George (Sheffield); **Winterborne,** Reginald Eric (Sheffield); **Worthington,** Gordon Selby (West Bromwich); **Wynne,** Edward Jeffrey (Newcastle-on-Tyne).

The **President** declared the candidates to be duly elected. They numbered 138, and the total membership of the Institute was now 4872.

INDUCTION OF THE PRESIDENT-ELECT

Mr. **R. G. Lyttelton,** the Retiring President, before vacating the Chair, introduced the new President, Sir Charles Bruce-Gardner, Bt.

VOTE OF THANKS TO THE RETIRING PRESIDENT

The **President** (Sir Charles Bruce-Gardner) then proposed a vote of thanks to the Retiring President, which was seconded by Dr. **H. H. Burton,** C.B.E., and carried unanimously, with acclamation.

PRESIDENTIAL ADDRESS

The new **President** then delivered his Presidential Address, published in the May, 1955, issue of the *Journal*.

VOTE OF THANKS TO THE PRESIDENT FOR HIS ADDRESS

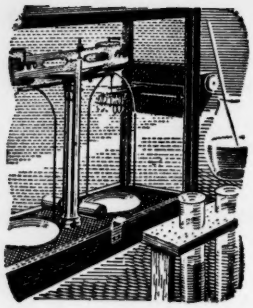
Mr. **James Mitchell,** C.B.E., proposed a vote of thanks to the President for his Address, which was seconded by Mr. **R. Mather** and carried unanimously, with acclamation.

MEMBERS' DINNER

The Annual Dinner was held at Grosvenor House, Park Lane, London, W.1, on Wednesday, 27th April, 1955. The Rt. Hon. VISCOUNT SWINTON, G.B.E., C.H., M.C., proposed the toast of "The Iron and Steel Institute and Industry," to which the PRESIDENT replied. The toast of "The Guests" was proposed by Captain H. LEIGHTON DAVIES, C.B.E., and the response was made by the Rt. Hon. VISCOUNT CHANDOS, D.S.O., M.C.

PRESENTATION OF PAPERS

A list of the papers presented and discussed at the Annual General Meeting was given in the April issue of the *Journal* on p. 372.



PAPERS AND REPORTS ON RESEARCH AND PRACTICE

Metallurgy · Plant Operation · Research

The Viscosity of Liquid Iron and Iron–Carbon Alloys

By R. N. Barfield and J. A. Kitchener

SYNOPSIS

The oscillating crucible method has been used to determine the viscosity of liquid iron and iron–carbon alloys up to 4·4% C. Carbon markedly reduces the viscosity, but increases the activation energy for flow. Sulphur has a much smaller effect. 1152

IN RECENT YEARS numerous papers have been published concerning thermodynamic properties of liquid steel. To give a theoretical interpretation to the results of these measurements, it is desirable to have information on non-thermodynamic properties of solutions in liquid iron, for example self-diffusion,[1] density, and viscosity. It is also of fundamental interest to have experimental values for the viscosity of pure iron at various temperatures to compare them with predictions made from theories on the viscosity of pure liquids. Finally, a knowledge of the effects of temperature and composition on the viscosity of iron alloys is useful from a technological viewpoint, as viscosity is one of the factors determining the ability of the metal to flow into casting moulds.[2] The present paper reports some measurements of the viscosity of pure iron and iron–carbon alloys.

EXPERIMENTAL

Meyer's method[3] is particularly suitable for viscosity measurements of moderate accuracy at high temperatures owing to the simplicity of the apparatus. The liquid is contained in a cylindrical crucible which performs torsional oscillations under the control of an elastic wire or bifilar suspension. Hopkins and Toye[4] have shown that the viscosity can be calculated from the logarithmic decrement of the oscillations, the density of the liquid, and the physical constants of the apparatus. Their method of calculation was followed in the present work.

Figure 1 is a half-sectional view of the suspended system. The crucible (*G*) containing the metal was of recrystallized alumina (Morgan Crucible Co., type XN 100). Two diametrically opposite egg-shaped holes were cut in the sides of the crucible near the rim with a diamond drill and it was suspended from a molybdenum **T**-piece (*F*) screwed to the bottom of a ¼-in. dia. molybdenum rod (*E*). The top of this rod was attached to a pin chuck (*C*) which held the suspension wire (*S*), and to an aluminium disc (*D*) having 400 divisions engraved around its edge. The suspension wire was of a Be–Cu alloy 0·09 in. dia. and was attached to a torsion head (*A*) by a pin chuck (*B*). Slight rotation of the centre spindle of the torsion head set the crucible in oscillation, and the amplitudes of the swings could be observed by a telescope focused on the graduations on the disc (*D*). The torsion head rested on a bracket fixed to the wall of the laboratory. This prevented any disturbances in the rest of the apparatus from reaching the suspended system.

A half-sectional view of the furnace is shown in Fig. 2. The element (*J* and inset *a*) was made from a graphite tube of 3 in. internal dia. cut longitudinally as described by Burton and Mayorcas.[5] The two legs (*K*) at the top of the element were clamped to two water-cooled copper blocks (*L*). Four pipes (*M*) carrying the cooling water passed through insulating and gas-tight bushes in the top plate of the furnace and served as current leads. The element was surrounded by carbon powder with an alumina tube and alumina powder beyond that, and excessive heat loss upwards was prevented by four molybdenum radiation shields (*N*). The temperature was measured by thermocouples in alumina sheaths (*H*). Both W/Mo and Pt–20% Rh/Pt–40% Rh couples were used during the work. The former are much cheaper and quite satisfactory once a batch of the wire has been calibrated, but the wires become very brittle during use. The furnace could reach 1900° C. with an applied power of 3 kW. and had a zone of 2½ in. in the lower

Paper C/9/55 of the Chemistry Department of the British Iron and Steel Research Association, received February, 1955.

Mr. Barfield is now with the National Research Council, Ottawa, Canada, and Dr. Kitchener is at the Department of Chemistry, Imperial College of Science and Technology, London.

half of the element where the temperature was constant to within $\pm 5^\circ$ C.

The furnace case was supported in a framework which permitted it to slide vertically up and down. With it in the raised position the crucible was in the even temperature zone of the furnace, and the top of the furnace could be bolted to the bottom flange (*P*) of a water-cooled jacket (*Q*) surrounding the suspension rod (*E*). This jacket was fixed to the framework. When the furnace was lowered, the crucible was accessible for removal.

The whole suspended system was surrounded by a gas-tight enclosure and, to prevent oxidation, a mixture of nitrogen with a small amount of hydrogen was passed into the bottom of the furnace. The gas emerged through an outlet in the torsion head.

Hopkins and Toye[4] gave the following formula for the calculation of the viscosity by the oscillating crucible method:

$$\frac{I}{T}\left(\lambda - \lambda_0\right)\left(\frac{T^2}{T_0^2} + 1\right) = \pi\eta\left[-ca^2\left(2 - \mu\phi(\mu)\right) - K(\mu)\right]$$

where I = the moment of inertia of the empty system
λ_0 = logarithmic decrement of the empty system
λ = logarithmic decrement of the full system
T_0 = period of the empty system
T = period of the full system
η = viscosity
c = height of liquid in the crucible

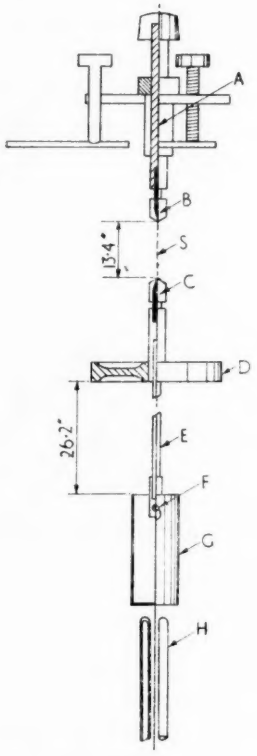


Fig. 1—Half-sectional view of suspended crucible system

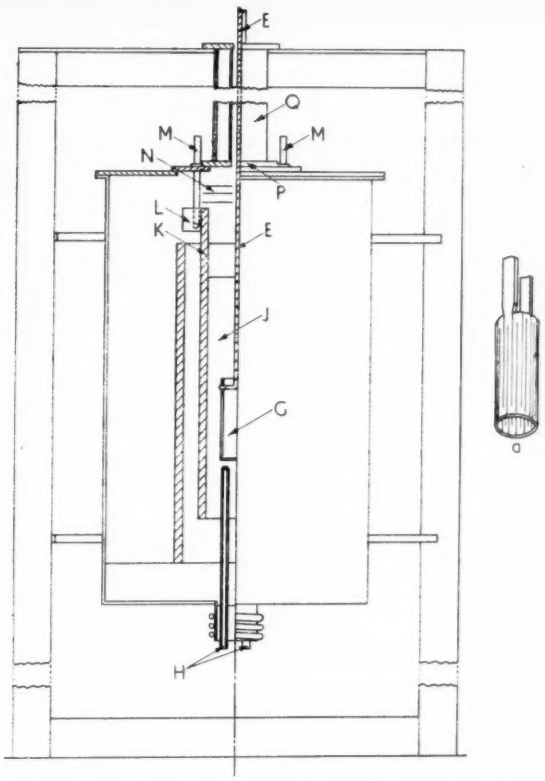


Fig. 2—Half-sectional view of furnace; inset, heating element

a = radius of the crucible
$\mu = \left(\frac{\pi a^2\rho}{T\eta}\right)^{\frac{1}{2}}$
ρ = density of the liquid
$\mu\phi(\mu)$ = real part of $\zeta\left[\frac{J_0(\zeta)}{J_1(\zeta)}\right]$

J_0 and J_1 are Bessel functions of the first kind and of order 0 and 1, respectively

$\zeta = \mu(1 - i)$

$K(\mu)$ = real part of $2\zeta^4 \sum \frac{\tanh l_n c}{l_n k_n^2[(ak_n)^2 - \zeta^2]}$

k_n are the roots of $J_1(k_n a) = 0$ and the summation is taken from $n = 1$ to $n = \infty$.

$l_n = (\zeta^2/a^2) - k_n^2$

Crucibles were checked for roundness and internal symmetry with a set square and internal callipers. The radius a was found by measuring with a depth gauge the changes in depth occurring on adding known weights of mercury. A correction was made to allow for the expansion of the crucible at the temperature of the experiment.

The moment of inertia (I) was found by placing weights of known dimensions on the disc and finding the period of oscillation; I was calculated from the period of the system without the weights and the position and dimensions of the weights. The periods were measured with a stop-watch, using transits on a scale of a spot of light reflected by a small mirror fixed on the suspension system just above the disc (*D*). The logarithmic decrements were calculated from

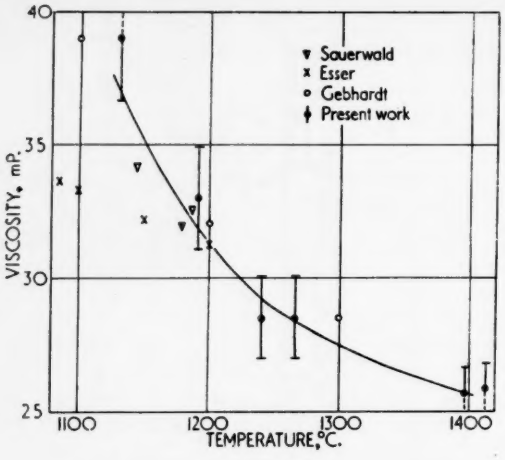


Fig. 3—Copper: viscosity *v.* temperature

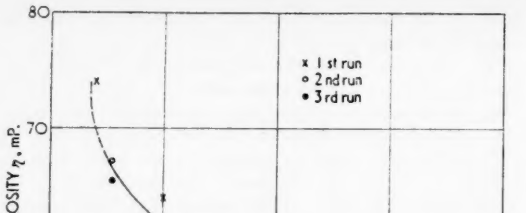


Fig. 4—Pure iron: viscosity *v.* temperature

successive maximum deflections of the disc (*D*) as observed through the telescope. The height of the liquid was calculated from its weight and density and the radius of the crucible. Density values for iron and iron–carbon alloys were taken from a paper by Benedicks, Ericsson, and Ericson.[6]

To test the apparatus and method of calculation, the viscosity of ' Analar ' tin was measured at several temperatures between 258° and 500° C. The results agreed to within 1% with those of Sauerwald,[7] who used a capillary-tube method, and Stott,[8] who extended the range of Sauerwald's measurements using an oscillating disc viscometer.

The viscosity of electrolytic copper was determined between 1130° and 1405° C. and the results are shown in Fig. 3, together with those of Sauerwald,[9] Esser,[10] and Gebhardt.[11] The values obtained show considerable differences from those of other workers, especially at the low-temperature end of the range covered; however, previous investigations have not been sufficiently accurate to establish reliable viscosity values for liquid copper.

The viscosities of pure iron was determined between 1540° and 1855° C., using high-purity iron provided by B.I.S.R.A. Two different samples were used: *AA* iron, a pure Swedish iron containing 0·02% C, 0·02% Si, and smaller percentages of other impurities, and *AH* (de-oxidized) iron containing 0·06% total impurity. Three independent determinations were carried out. The results obtained (Fig. 4) agree to within the limits of experimental error (± 2%). Since small amounts of impurities do not seem to affect the viscosity appreciably, it is unlikely that the small amounts of H_2 and N_2 present in the iron will affect the viscosity outside the limits of experimental error.

Analysis of samples of iron after the experiments had been made showed that 0·03–0·09% carbon had been picked up, presumably from the graphite heating element by way of methane in the furnace atmosphere. The effect on the viscosity is less than the experimental error. Contamination of the pure iron by aluminium from the alumina crucible was negligible—less than 0·001%.

The viscosities of alloys containing 0·75% C, 2·10% C, 2·52% C, 2·55% C, 3·40% C, 3·43% C, and 4·40% C were also determined. Analyses, made (by B.I.S.R.A. laboratories) after the experiments, showed that less than 0·005% Al was picked up from the crucible during the experiments. Figure 5 shows the viscosity plotted against temperature for the various

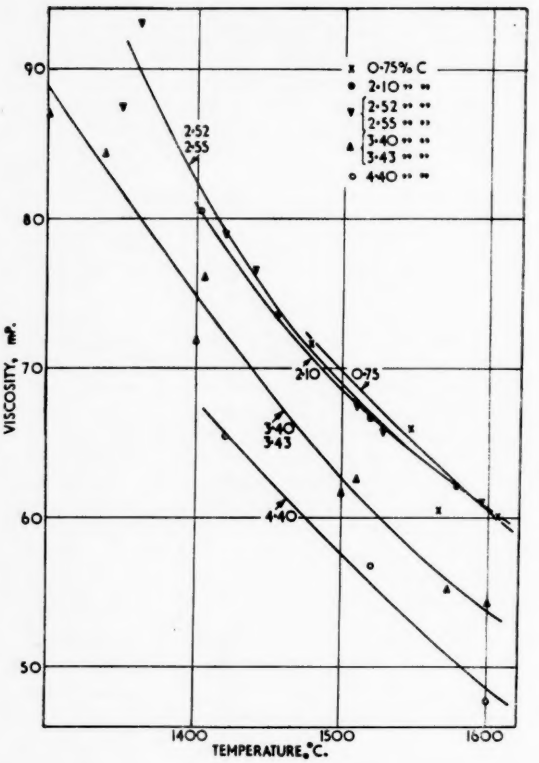


Fig. 5—Iron–carbon alloys: viscosity *v.* temperature

alloys, and Fig. 6 shows isotherms of viscosity against weight percentage of carbon.

An attempt to determine the viscosity of a melt containing 5·5% C gave unreliable results as this concentration was found to produce considerable attack on the alumina crucible. The crucible walls were corroded and the final melt contained 3·4% C and 1·84% Al.

The viscosity of an alloy containing 1·16% S and 0·02% C was determined between 1530° and 1800° C. As no density values were available for this alloy, the density was calculated on the assumption that solutions of sulphur in iron are substitutional and that no volume change occurs when a sulphur atom is substituted for an iron atom. The results are shown in Fig. 7.

DISCUSSION

The only previous measurements on pure iron are those of Losana,[12] who measured the viscosity of electrolytic iron between 1550° and 1700° C. He measured the logarithmic decrement of torsional oscillations of a spindle suspended in the melt. In calculating his results, Losana apparently did not allow for the fact that the logarithmic decrement is not only a function of the viscosity of the liquid but also of the density, and so his results are probably unreliable.

Many theories of the viscosity of liquids (e.g. those of Andrade,[13] Eyring,[14] and Frenkel[15]) lead to a relationship between the viscosity and the absolute temperature of the form,

$$\eta = A \exp(E/RT)$$

where η = viscosity, E = energy of activation for viscous flow, T = absolute temperature, and R = gas constant per mole. Figure 8 shows log η plotted against $(1/T) \times 10^4$ for pure iron. The broken line A was calculated by the method of least squares, ignoring the point furthest to the right (corresponding to 1540° C.). This line is found to pass within σ (σ = standard deviation) of 5 points and within 2σ of all the points. If the distribution of errors is normal and the number of points is large, statistical theory requires 68% of the points to be within σ of the line; so in the present case it is probably justified to join the points by a straight line. The slope of the line is 0·149, and assuming that $\eta = Ae^{E/RT}$, E is found to be 6·8 ± 0·5 kcal./mole. The value for the latent

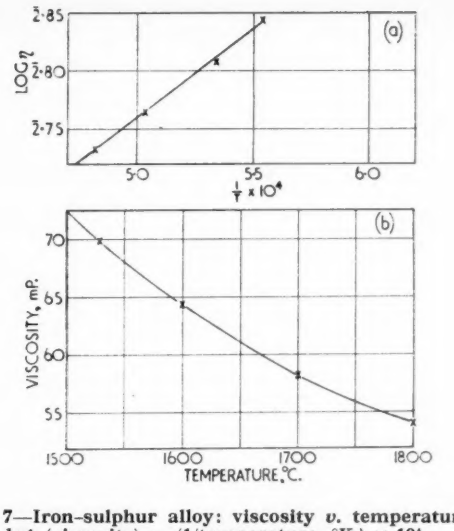


Fig. 7—Iron–sulphur alloy: viscosity *v.* temperature; log (viscosity) *v.* (1/temperature, °K.) × 10^4

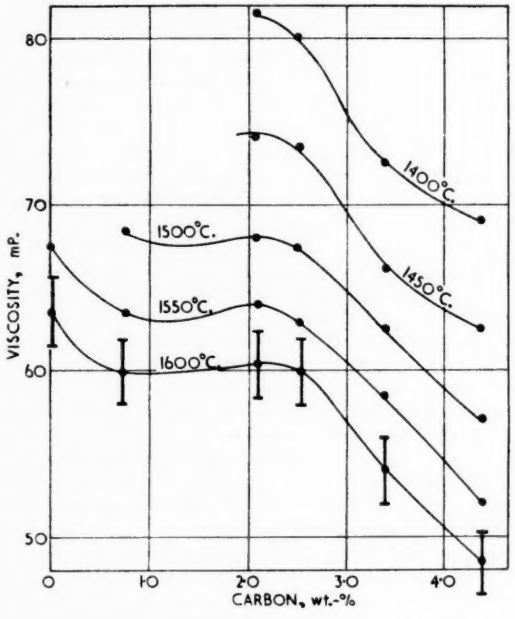


Fig. 6—Iron–carbon alloys: viscosity *v.* % carbon

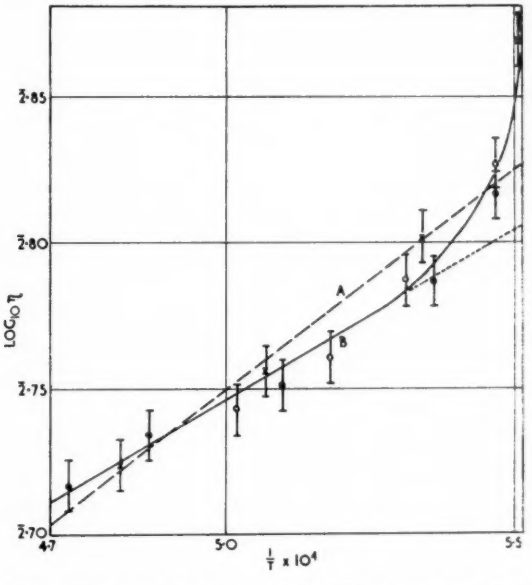


Fig. 8—Pure iron: log (viscosity) *v.* (1/temperature, °K.) × 10^4

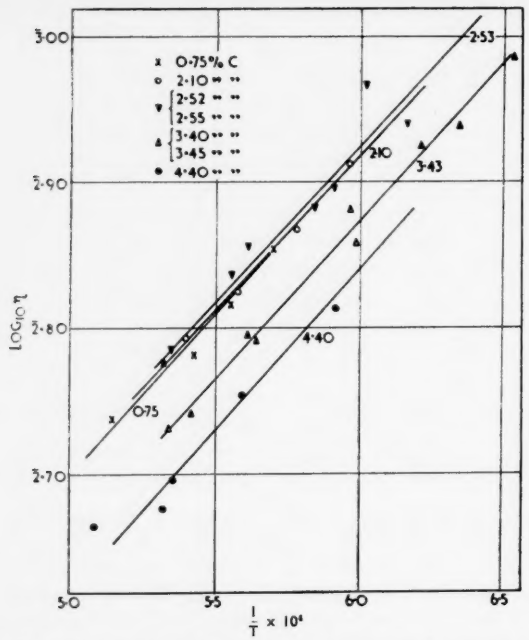


Fig. 9—Iron–carbon alloys: log (viscosity) *v.* (1/temperature, °K.) × 10^4

heat of evaporation of liquid iron has been estimated to be 88 kcal./mole[16]; hence the ratio

$$\frac{\text{Energy of vaporization per mole}}{\text{Energy of activation for viscous flow per mole}} = 13$$

which is within the range of values found to exist for other metals.[13] The reading at 1540° C. is very close to the melting point (1537° C.).[17] Since the expected accuracy of temperature measurement was ± 5° C., this point is of doubtful reliability as partial solidification may have occurred. Another possibility is that the simple exponential equation does not hold near the melting point. Yao and Kondic[18] found this to be so for Sn, Pb, Zn, and Al. However, in the present case it would not be justifiable to draw a conclusion of this sort.

The viscosity at 1537° C. found by extrapolating the line *A* of Fig. 8 is 0·067 ± 0·0015 poise; that from line *B* is 0·064. Andrade[13] proposed the following equation for the viscosity of a simple liquid at its melting point:

$$\eta = 5{\cdot}1 \times 10^{-4}(A\,T_m)^{\frac{1}{2}}/V^{\frac{2}{3}}$$

where A = atomic weight, V = volume of a gram atom, and T_m = melting point. The melting-point viscosity of iron calculated from this formula is 0·0415 poise.

Previous measurements on the viscosity of iron alloys have been made by Thielmann and Wimmer[19] (white cast iron), Esser, Greis, and Bungardt[10] (white cast iron), and Shvidkovski *et al.*[20] (various steels). All these authors conclude that addition of carbon to the melt lowers the viscosity, but the values obtained cannot be compared directly with the present ones owing to the presence of other alloying elements besides carbon.

The curves of Fig. 6 are drawn through the mean values found for the viscosity. When the probable error of each point is taken into account (as in the 1600° C. curve), it is possible to represent the results by two straight lines intersecting at in the region of 2·0–2·5% carbon. Measurements of several other binary alloys have shown peculiarities at compositions corresponding to the limit of solid solubility of one phase in another, and it may be significant that 1·98% C is the limit of solid solubility of carbon in austenite.

Measurements made on the flow of iron–carbon alloys into moulds[21] show that the casting fluidity at constant temperature falls rapidly as the carbon content is increased from 0 to 0·1%. As more carbon is added, the casting fluidity rises rapidly, and between about 0·8 and 2% carbon it remains constant. Further additions of carbon up to 3·0% raise the fluidity. It will be noticed that in the range 0·8–3·0% the viscosity isotherms of Fig. 6 behave in a corresponding manner as viscosity is the reciprocal of fluidity.

Graphs of log η *v.* $(1/T) \times 10^4$ for different carbon contents are shown in Fig. 9. It is possible to join the points for each composition by straight lines which have equal slopes to within the limits of experimental error. The activation energy E in the equation $\eta = Ae^{E/RT}$ is 10·2 ± 0·9 kcal., and is seen to be greater than that found for pure iron.

Current theories of viscosity are too nebulous to permit any precise interpretation of the experimental results: the chief uncertainty is the precise unit which moves in viscous flow. It is certainly not possible to deduce directly from the results details of the structure of the solution. The simplest approach seems to be the 'hole' theory first suggested by Frenkel,[15] in which the liquid is regarded as similar to a solid with vacant lattice sites. Carbon dissolves interstitially in solid iron and, because the size of the carbon atom is slightly larger than the interstice, a strain is set up and a small expansion occurs.[22] If carbon atoms cause similar 'strains' in the liquid, it seems reasonable to assume that holes will tend to occur in the neighbourhood of the carbon atoms. If the carbon atoms exert a binding on the iron atoms, then since the iron atoms can only flow where there is a hole, the activation energy will be greater when there is carbon present than when there is not. The addition of carbon also causes an expansion and hence will increase the number of holes. This will tend to cause an increase in fluidity. It is possible that these two effects caused by the addition of carbon (increase in activation energy resulting in an increase of viscosity, and increase in volume resulting in a decrease in viscosity) combine to produce the observed viscosity/composition relationship.

Figure 7 shows graphs of viscosity against temperature and log η against $(1/T) \times 10^4$ for iron containing 1·17% sulphur. Below 1560° C., the viscosity is slightly greater than that for iron. The activation energy for this alloy is 7·15 kcal./mole, which is the same as that for iron to within the limits of experimental error. This suggests that the mechanism of flow is the same as that for pure iron, a conclusion which is consistent with the hypothesis that, unlike

carbon, sulphur atoms dissolve substitutionally in iron.

Acknowledgments

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Yield Behaviour of Metals at Low Temperatures

WITH PARTICULAR REFERENCE TO SOME CARBON AND LOW-ALLOY STEELS

By H. F. Hall, B.Sc.(Eng.), and R. W. Nichols, B.Met.

SYNOPSIS

The tensile and impact properties of a series of carbon steels in the quenched and tempered. furnace-cooled, and as-rolled conditions were determined at several temperatures between + 200° and −197° C. Similar tests were also made on three low-alloy steels and two non-ferrous alloys.

The proof-stress values for the steels were found to increase markedly with decrease in temperature, this increase being greater in those materials having the lower room-temperature proof-stress values. For most of the materials tested decrease in temperature also increased the difference between the upper and lower yield point. the yield extension, the elastic modulus, the ultimate stress, and, except in the temperature range over which the tensile ductility decreased markedly with decrease in temperature, the breaking stress.

The tensile and impact properties were compared and it was found that the room-temperature reduction in area provided some index to the Charpy maximum energy of a material, but there was no direct correlation between any of the tensile properties and the impact transition temperatures. This lack of correlation was explained in terms of the flow and fracture stress concept of brittle fracture, and dynamic factors calculated from the results on this basis showed reasonable agreement with experiment.

1060

IT IS WELL KNOWN that ferritic steels show a marked decrease in toughness associated with decrease in temperature, and a large amount of research has been devoted to a study of this phenomenon. Most of the results available in the literature, however, have been obtained by means of the notched-bar impact test, and comparisons of these results with low-temperature tensile properties have been relatively few. It was thought, therefore, desirable to carry out, in similar materials, both notched-bar impact and slow-speed tensile tests, using apparatus suitable for studying the effect of temperature on the early stages of plastic deformation. The purpose was to reveal any points of correlation between these two forms of test which would enable a fuller interpretation of the notched-bar test to be made in terms of working conditions.

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The authors are with the Ministry of Supply Armament Research Establishment, Woolwich.

MATERIALS, APPARATUS, AND EXPERIMENTAL TECHNIQUE

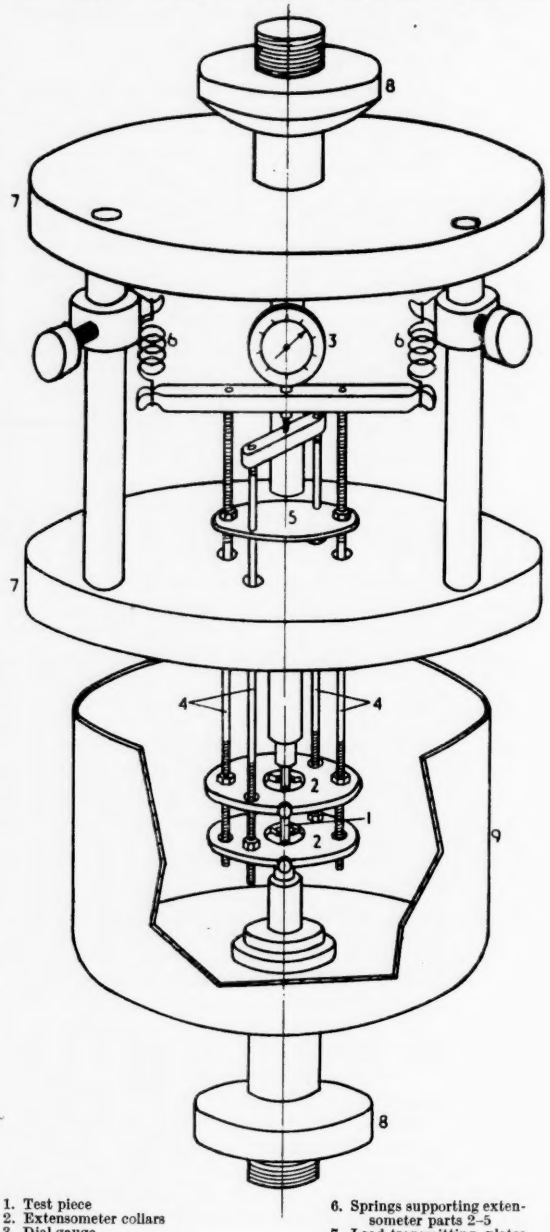
The materials tested were intended to cover a wide range of impact properties, and included a series of carbon steels, alloy steels, copper, and aluminium alloys. The analyses and heat-treatments of these materials are shown in Table I. The 0·15%, 0·3%, and 0·7% carbon steels were tested in the as-rolled in addition to the heat-treated conditions. The as-rolled steels were of A.S.T.M. grain size 8–9 with ferrite–fine-pearlite structures.

The tensile tests were carried out on a 35-ton capacity Losenhausen hydraulic machine with pendulum-type load-measuring equipment. The specimens had carefully turned threaded ends and were in general accordance with B.S.18 : 1950, the diameter of the parallel portions in the earlier tests being 0·564 in. For some steels it was found necessary to reduce this to 0·395 in. to prevent fracture occurring across the threaded portions.

The load was applied through a spherical seat in the straining crosshead to a load-transmitting member, which enabled the extensometer dial gauge to be mounted co-axially with and above the specimen (*see* Fig. 1). The extensometer consisted of two collars fitted with set screws, by which they were attached to the specimen at the required gauge distance apart. Each collar was rigidly connected by a pair of vertical screwed rods passing up through clearance holes in the lower plate of the load-transmitting member to a horizontal cross-bar located centrally above the test piece. The two cross-bars were disposed at slightly different heights, the upper one to support the body and the lower to actuate the spindle of a dial gauge graduated in 0·0001-in. divisions; this gauge was the only magnifying device in the system. The whole instrument was suspended by springs attached to its upper cross-bar, the extensometer set-screws thus being relieved of the weight of the instrument. The specimen was subjected to continuous straining throughout the test and simultaneous readings of the load and extension gauges were taken at appropriate intervals. The strain rate was controlled manually in conjunction with stopwatch observations and the average strain rate was 2×10^{-4} per sec. The test conditions necessitated a slower strain rate over the elastic range, the average rate in this range being $0{\cdot}13 \times 10^{-4}$ per sec.

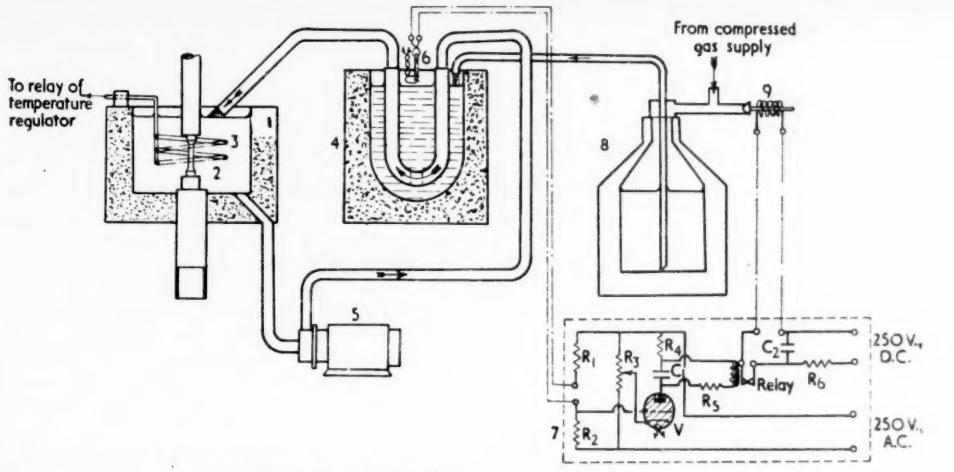
The tests were carried out with the specimen completely immersed in coolant, which was kept in rapid circulation by a centrifugal pump. In the temperature range + 30° to −70° C. the circulating fluid used was alcohol cooled in an external bath by direct addition of solid carbon dioxide. For temperatures between −70° and −150° C. commercial pentane or *iso*pentane was used, this fluid being cooled by passing through a **U**-shaped heat exchanger containing liquid nitrogen. The temperature drop across the cooler and the approximate temperature of the bath were governed by the controlled level of the liquid nitrogen, which was kept sufficiently low to prevent freezing of the pentane.

The temperature of the bath was measured by a resistance thermometer and controlled by a potentiometric recorder which governed the on–off period of an annular electric heater in the testing bath. Temperatures of −186° and −197° C. were obtained by filling the testing bath with liquid air and liquid nitrogen, respectively. To maintain a constant level of liquified gas in the testing bath or heat exchanger the electronic controller shown schematically in Fig. 2 was used. When the liquid touched the tip of a thermistor fitted at the required level in the chamber, the resistance of the thermistor increased markedly, altering the grid voltage on a gas-filled



1. Test piece
2. Extensometer collars
3. Dial gauge
4. Rods connecting 2 with 3
5. Guide plate for 4
6. Springs supporting extensometer parts 2–5
7. Load-transmitting plates
8. Self-aligning loading nuts
9. Vessel for liquid coolant

Fig. 1—Apparatus for tensile test



1. Testing bath
2. Test piece
3. Temperature-control heater
4. Heat exchanger
5. Centrifugal pump
6. Adjustable liquid nitrogen level element (Stantel F2200 thermistor)
7. Liquid nitrogen level control unit
8. Vacuum-insulated liquid nitrogen storage vessel
9. Magnetic vent valve

Circuit Values

R_1	10,000 Ω resistance	R_6	500 Ω resistance
R_2	500,000 Ω ,,	C_1	10 μF. condenser
R_3	6000 Ω ,,	C_2	10 μF. ,,
R_4	1000 Ω ,,	V_1	GTIC valve
R_5	5000 Ω ,,	Relay	24 V., 500 Ω

Fig. 2—Schematic diagram for cooling system

triode. This allowed a solenoid-operated vent valve to open, which released the gas pressure in the Dewar vessel and stopped further flow of liquid. A small heater coil around the tip of the thermistor caused this to heat up rapidly when it was no longer immersed, closing the vent valve again. This system proved very satisfactory even when the liquid was boiling vigorously.

The notched-bar impact tests were carried out on a Charpy 30-kg.m. machine using specimens 10 mm. square × 55 mm. long with a standard Izod **V**-notch at mid-length. The specimens were maintained at

Table I
MATERIALS TESTED

Specimen Designation	Heat-Treatment	Analysis, %								
		C	Mn	Si	S	P	Ni	Cr	Mo	Al
0·15% carbon steel: As-rolled	Hot-rolled 1-in. bar									
Annealed	Furnace-cooled from 880° C.									
Tempered	Oil-quenched from 880° C. 1-in. bar Tempered 650° C. for 1 hr.	0·15	0·74	0·15	0·033	0·032	0·29	0·05	0·04	<0·005
0·30% carbon steel: As rolled	Hot-rolled 1-in. bar									
Annealed	Furnace-cooled from 860° C.									
Tempered	Oil-quenched from 860° C. Tempered 650° C. for 1 hr.	0·31	0·73	0·15	0·035	0·024	0·07	0·06	<0·01	<0 005
0·55% carbon steel: Tempered	Oil-quenched from 880° C. Tempered 650° C.	0·55	0·66	0·25	0·032	0·039	0·18	0·06	...	<0·005
0·70% carbon steel: As-rolled	Hot-rolled 1-in. bar									
Annealed	Furnace-cooled from 820° C.									
Tempered	Oil-quenched from 820° C. Tempered 650° C. for 1 hr.	0·69	0·87	0·24	0·029	0·029	0·08	0·07	0·02	<0·005
0·6% carbon, 1·2% manganese steel: Annealed	Furnace-cooled from 820° C.									
Tempered	Oil-quenched from 820° C. Tempered 650° C. for 1 hr.	0·62	1·21	0·23	0·024	0·026	<0·01	0·08	<0·01	<0·005
3% nickel, 0·7% chromium steel: Tempered	Oil-quenched from 860° C. Tempered 635° C.	0·35	0·57	0·24	0·030	0·021	3·08	0·67	0·50	<0·005
5% nickel steel: Annealed	Furnace-cooled from 820° C.									
Tempered	Oil-quenched from 820° C. Tempered 650° C. for 1 hr.	0·39	0·80	0·09	0·040	0·019	5·03	0·01	0·01	<0·005

Copper	Cold-worked	Sn 0·004	Fe 0·0001	Zn <0·01	All other elements < 0·005% (spectrographic)					
Aluminium alloy	Wrought, solution-treated	Cu 3·93	Fe 0·44	Mn 0·56	Si 0·48	Mg 0·73	Zn 0·10	Ni 0·03	Sn 0·02	

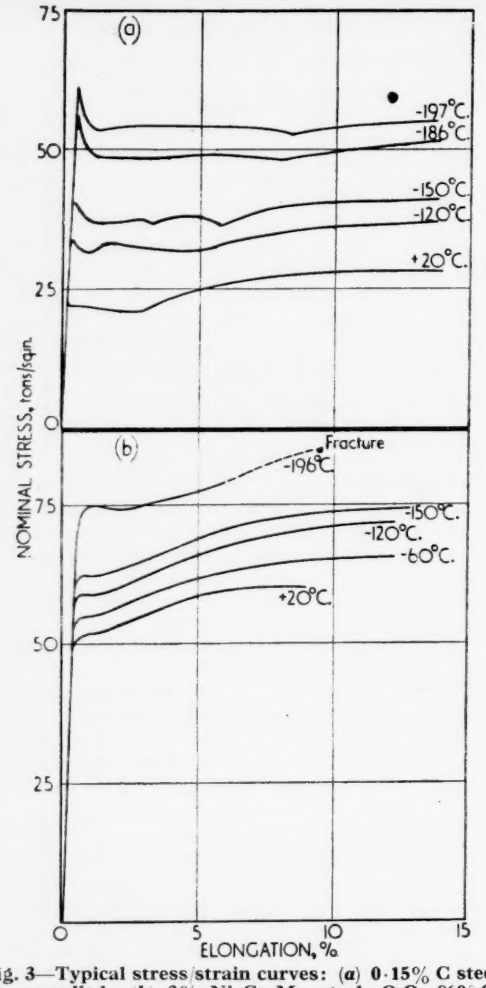


Fig. 3—Typical stress/strain curves: (*a*) 0·15% C steel, as-rolled; (*b*) 3% Ni–Cr–Mo steel, O.Q. 860° C., T. 635° C.

the desired temperature in a suitable liquid bath and transferred to the testing machine as required. The specimens were broken within 4 sec. of removal from the bath, it having been shown[1] that no appreciable temperature change occurs in this period. In addition to noting the energy absorbed, the fractures were examined and the areas of fibrous and crystalline appearance were each approximately measured.

Nominal-stress/nominal-strain curves were obtained from the tensile tests up to about 5% strain in the earlier tests, and improvements in the extensometric technique allowed these curves to be extended to higher strain values in the later tests. Typical sets of these curves are shown in Fig. 3. The variation with temperature of various tensile properties, together with the Charpy-energy/temperature curves, are shown in Fig. 4. These curves represent the average values, the actual values obtained in the Charpy test at a given temperature being within ± 5 ft.lb. at the higher energy values and ± 0·5 ft.lb. at the minimum energy values. The reproducibility of the tensile test results was good except for the breaking stress and ductility measurements at the lowest temperatures, where max. differences of ± 6 tons/sq. in. and ± 3% respectively were experienced.

VARIATION OF TENSILE PROPERTIES WITH TEMPERATURE

Young's Modulus

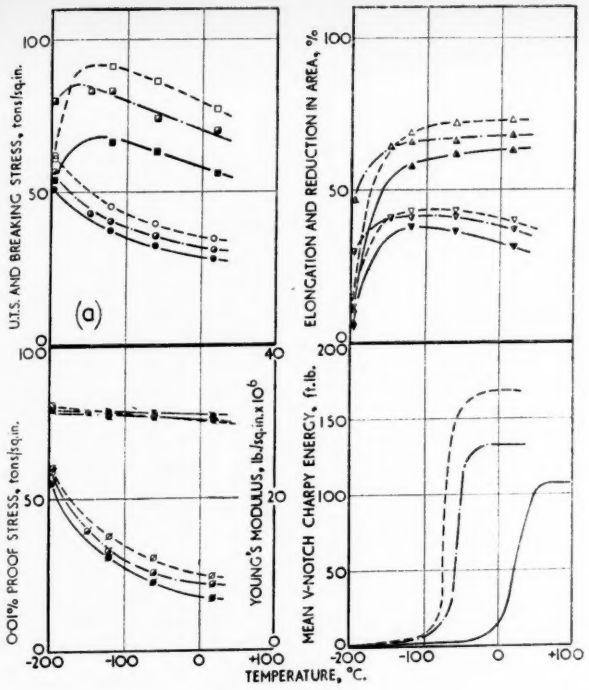
The modulus values obtained from the stress/strain records were found to increase continuously as the temperature of test was decreased, and for most of the materials tested the relationship was approximately linear. The rate of increase varied considerably between the different materials, and for the carbon steels it was rather greater for the tempered materials than for the annealed. The average value of the temperature coefficient $(\Delta E)/(E\Delta T)$ for the carbon steels was $-23{\cdot}1 \times 10^{-5}$ per ° C., which is in general agreement with the results of Keuligan and Houseman,[2] who used a vibration method.

Proof Stress and Yield Point

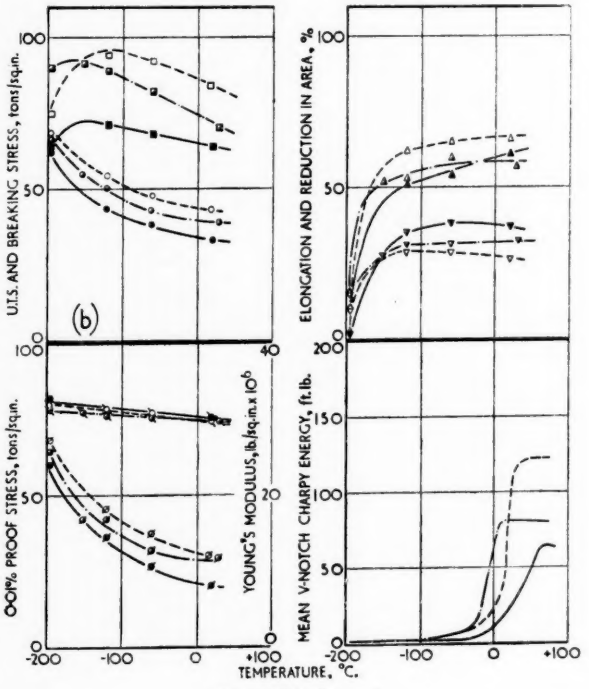
The values of the 0·01% proof stress for the carbon steels increased continuously as the test temperature was lowered, the rate of increase being more rapid at the lower temperatures. The ratio (0·01% proof stress at −197° C.) *v.* (0·01% proof stress at + 20° C.) was found to be smaller for materials showing higher values of the room-temperature proof stress, the values for the carbon and manganese steels in the as-rolled, annealed, and quenched and tempered conditions all lying on the same curve, as shown in Fig. 5. There was some indication that the proof stress in the alloy steels had a lower temperature variation than that in the carbon steels of similar strength, the 5% nickel steels also showing an anomalous decrease in proof stress on cooling from + 20° to −60° C. (Fig. 4*g*). The non-ferrous alloys showed a very small rate of change of proof stress with temperature (Fig. 4*h*).

Cottrell and Bilby[3] have explained the greater temperature variation of the yield point in iron in terms of the assistance given by thermal fluctuations to release of dislocations under external stress from their atmospheres of solute atoms, the activation energy for this process being proportional to the absolute temperature. Values of the activation energies corresponding to the experimental yield-stress values at the various test temperatures were obtained by use of the relationship given by Cottrell and Bilby, and the results (*see* Fig. 6) show reasonable agreement with the theory, although a certain ambiguity exists because of the difficulty of extrapolating the experimental results to zero temperature.

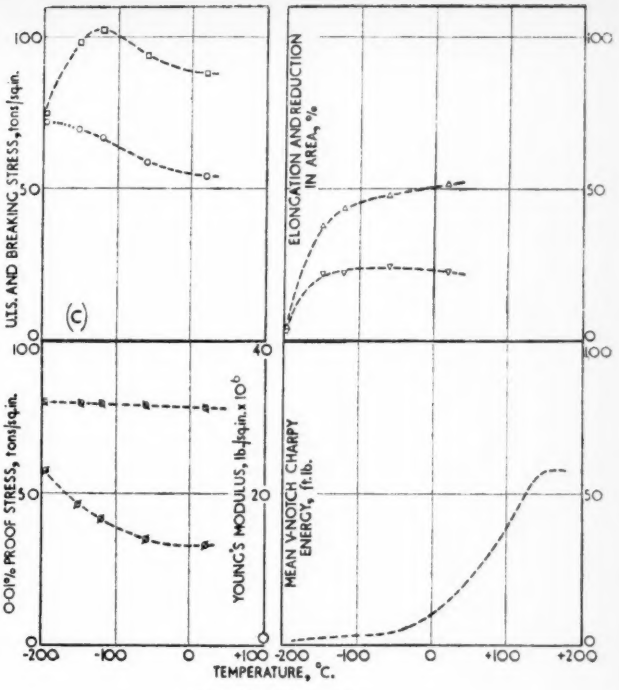
For most of the materials tested, the yield phenomena became more marked as the temperature of test was lowered. The 0·6% C, 1·2% Mn steel, which did not show a yield point at room temperature, did show it at lower temperatures. Many of the steels which showed the yield point at room temperature had increasing amounts of yield extension and increasing differences between the upper and lower yield stresses at lower temperatures. The fluctuation of the flow stress during yield extension also tended to be more marked at the lower temperatures.


U.T.S. AND BREAKING STRESS, tons/sq.in.
ELONGATION AND REDUCTION IN AREA, %
(a)
0·01% PROOF STRESS, tons/sq.in.
YOUNG'S MODULUS, lb./sq.in. x 10⁶
MEAN V-NOTCH CHARPY ENERGY, ft.lb.
TEMPERATURE, °C.

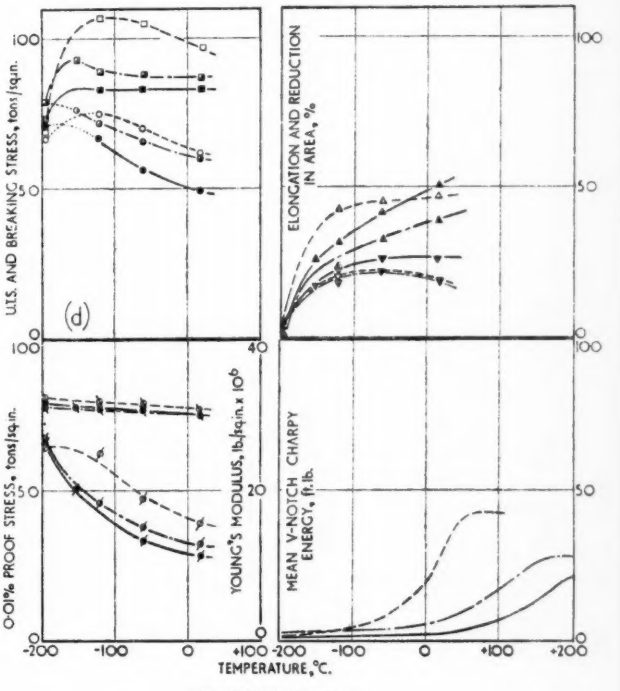
(*a*) 0·15% C steel


U.T.S. AND BREAKING STRESS, tons/sq.in.
ELONGATION AND REDUCTION IN AREA, %
(b)
0·01% PROOF STRESS, tons/sq.in.
YOUNG'S MODULUS, lb./sq.in. x 10⁶
MEAN V-NOTCH CHARPY ENERGY, ft.lb.
TEMPERATURE, °C.

(*b*) 0·30% C steel

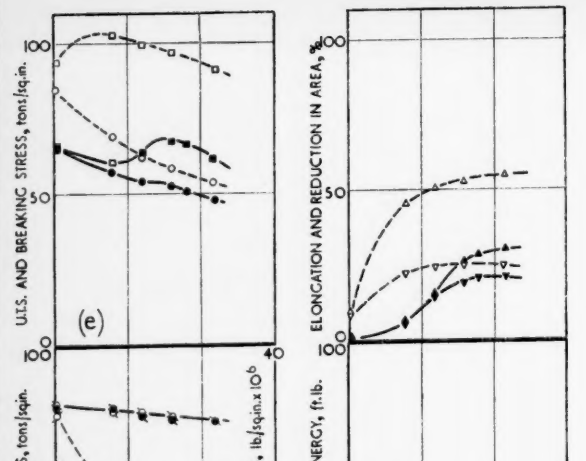

U.T.S. AND BREAKING STRESS, tons/sq.in.
ELONGATION AND REDUCTION IN AREA, %
(c)
0·01% PROOF STRESS, tons/sq.in.
YOUNG'S MODULUS, lb./sq.in. x 10⁶
MEAN V-NOTCH CHARPY ENERGY, ft.lb.
TEMPERATURE, °C.

(*c*) 0·55% C steel

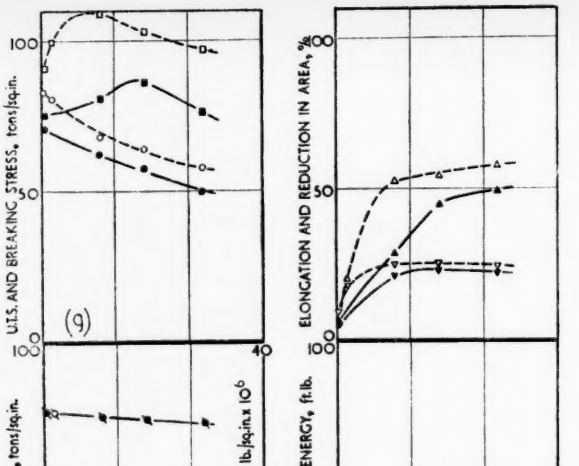

U.T.S. AND BREAKING STRESS, tons/sq.in.
ELONGATION AND REDUCTION IN AREA, %
(d)
0·01% PROOF STRESS, tons/sq.in.
YOUNG'S MODULUS, lb./sq.in. x 10⁶
MEAN V-NOTCH CHARPY ENERGY, ft.lb.
TEMPERATURE, °C.

(*d*) 0·70% C steel

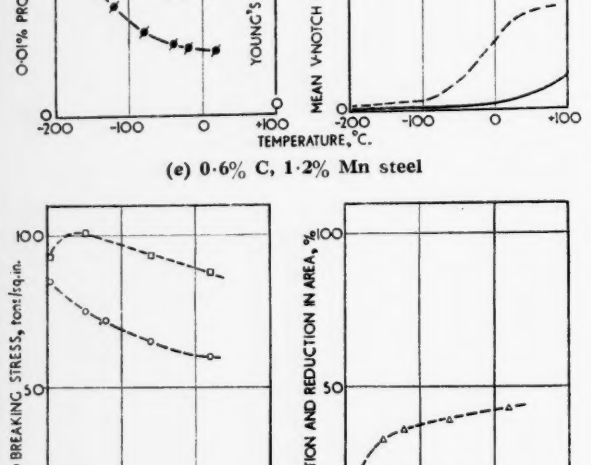
Fig. 4—Effect of temperature on mech



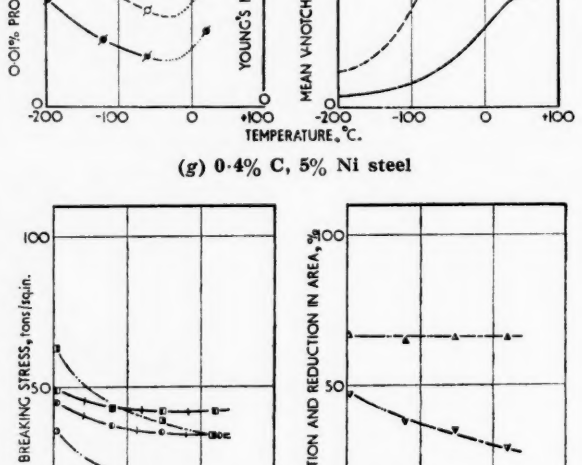
(*e*) 0·6% C, 1·2% Mn steel



(*g*) 0·4% C, 5% Ni steel



(*f*) 3% Ni, 0·7% Cr, 0·5% Mo steel


U.T.S. AND BREAKING STRESS, tons/sq.in.
(h)
ELONGATION AND REDUCTION IN AREA, %
0·01% PROOF STRESS, tons/sq.in.
YOUNG'S MODULUS, lb/sq.in. x 10⁶
MEAN V-NOTCH CHARPY ENERGY, ft.lb.
TEMPERATURE, °C.

(*h*) Non-ferrous alloys

□ Breaking stress
○ Ultimate stress
⌀ 0·01% proof stress
◇ Young's modulus
△ Reduction in area
▽ Elongation

□------□ Steels, O, Q, and T
□——□ Steels, as-rolled
■——■ Steels, annealed
□·····□ Copper
⊡——⊡ Al-Cu-Mg-Mn alloy

nical properties

[*Hall and Nichols*
[*To face p.* 332

Ultimate Stress

Throughout the range of temperature in which fracture of the tensile specimen occurred after necking, the ultimate stress increased continuously as the test temperature was lowered. For the carbon steels this increase with decrease in temperature was not as great as that shown by the 0·01% proof stress, and in general the proof-stress values at higher strains showed less effect of temperature than did the proof-stress values at lower strains. In the specimens of the lower-carbon steels tested at −197° C. the whole of the plastic strain took place at stresses below the upper yield stress, even in the cases where this strain was considerable and necking eventually occurred. In those tests where fracture occurred before any neck formed, the maximum-stress values did not show so marked an increase with decrease in temperature, an actual decrease occurring for the quenched and tempered 0·7% C steel specimens, because fracture occurred at smaller strains at the lower temperatures.

Breaking Stress

The breaking stress has been calculated on the basis of the area at the neck measured after fracture, which is liable to produce results higher than those obtained from area measurements taken during the test, owing to deformation in the process of fracture.[4] Moreover, the interpretation of the results is complicated by the triaxial tensile stresses at the centre of the neck in ductile specimens.

With decrease in test temperature the breaking stress increased to a maximum at a temperature corresponding to that for maximum elongation, and then decreased rapidly as the ductility decreased. As the temperature was further decreased below that needed to produce embrittlement, the breaking stress again increased (*see* Fig. 4*e*). These results suggest that the breaking stress is increased both by decrease in temperature and by plastic deformation. In these tests it was noted that the fracture appearance varied considerably with test temperature, but a similar type of breaking-stress/temperature curve was obtained by Bechtold and Scott[5] for Mo, whose fracture appearance was subject to less variation.

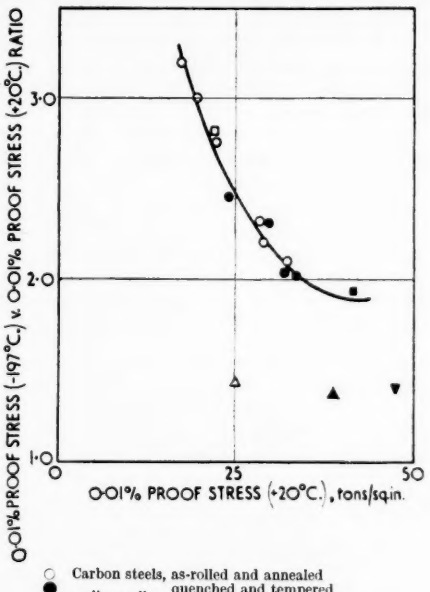


Fig. 5—Variation of effect of temperature on the 0·01% proof stress with its room-temperature value

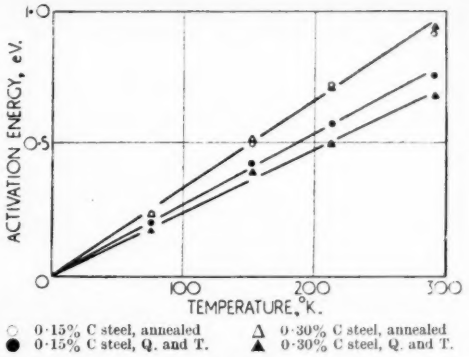


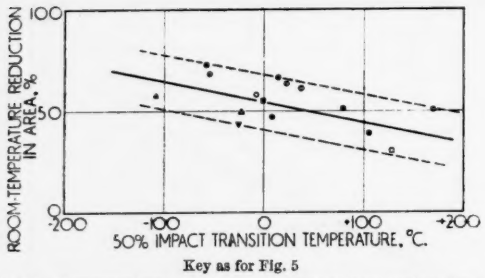
Fig. 6—Variation of activation energy for yield with temperature

Ductility

The reduction in area at fracture decreased with decreasing temperature for all the steels tested. The reduction-in-area/temperature curve for each steel showed a slight decrease at the higher temperatures followed by a more rapid decrease below about −80° C. The elongation/temperature curve in general showed, at the higher temperatures, a slight increase as the temperature of test decreased, followed at lower temperatures by a rapid decrease with decrease in the temperature. The temperature of maximum elongation corresponded to that of sharp decrease in the reduction in area. The initial increase of elongation resulted from greater pre-necking extension, due to an increase in the yield extension and in some cases an increase in the overall rate of strain hardening. The latter increase was shown more clearly in the stress/strain curves for the non-ferrous specimens than those for the steel specimens.

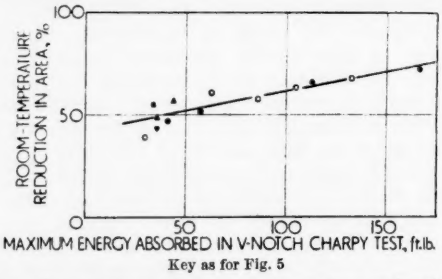
Fracture Appearance

At higher test temperatures most of the steels showed a normal cup-and-cone fracture; as the temperature was decreased the amount of shear fracture decreased. Many of the specimens with small amounts of shear fracture showed radial markings at the fracture face. These radial markings were made up of alternate sloping planes and axial planes and they became more intense at lower temperatures of test, giving a fracture of ' milling-cutter ' appearance. As the temperature was further lowered the reduction in area decreased and the radial steps became less clearly defined, the fracture becoming plane. Further decrease in temperature then increased the crystalline appearance of the fracture. The ' milling-cutter ' fracture bears some similarity to the ' star ' fracture reported by Hollomon



Key as for Fig. 5

Fig. 7—Comparison of room-temperature reduction in area to fracture in tensile test with V-notch impact transition temperature



Key as for Fig. 5

Fig. 8—Comparison of room-temperature reduction in area to fracture in tensile test with V-notch impact maximum energy

and Zener[6] and the longitudinal splitting observed by Hobson and Hewitt,[7] which were also intermediate between the cone and transverse fracture types. These types of fracture occur when the amount of failure by shear is restricted so that the fracture appearance is dominated by the stress-distribution effects at the neck and the manufacturing history of the specimen, in this case produced from rolled bar.

COMPARISON OF TENSILE AND NOTCHED-BAR IMPACT TEST RESULTS

Considering some results on ship-plate steels, Tipper[9] found that the room-temperature tensile property which showed the closest correlation with impact transition temperature was reduction in area. The present results support a similar conclusion, although there is a considerable divergence (*see* Fig. 7) from the linear relationship proposed by Tor, Stout, and Johnston.[10] A rather better proportionality exists between the reduction in area at room temperature and the corresponding Charpy maximum energy values (*see* Fig. 8), especially for the carbon steels.

Considering the tensile results at lower temperatures both reduction in area and elongation showed the sharp decrease over a relatively small temperature range which is characteristic of the notched-bar-impact-energy/temperature curves of ferritic materials. Most materials, however, showed little change in tensile ductility until the test temperature was less than −100° C., and the variation from one material to another was not marked.

Table II shows various brittleness criteria for the tensile and impact tests and the order of brittleness in which these criteria placed the various materials. No tensile criterion put the materials in exactly the same order as the 50% maximum impact energy criterion, the nearest approach to this order being made by the temperature at which the reduction in area value was one-half the room-temperature value. This temperature could not be obtained with great precision because of the practical difficulties of testing at temperatures between −150° and −190° C., a temperature range in which the reduction in area was for many of the steels very temperature-dependent. In a general way, however, there was a tendency for low values of this tensile transition temperature to be associated with low values of the impact transition temperature (*see* Fig. 9), although no general relationship appeared to exist. The tensile transition temperatures of the alloy steels were rather higher in relation to their impact transition temperatures than was the case in the carbon steels.

It can be explained qualitatively why there is no general relationship if the transition temperature for brittle fracture under given conditions of stressing is defined as that temperature at which the flow stress and the fracture stress have the same value under those conditions. If it is assumed, as Yokobori[12] has suggested, that the static-flow-stress/temperature relationship can be represented by

$$\log \sigma = \log \sigma_0 - aT$$

and the fracture-stress/temperature relationship by

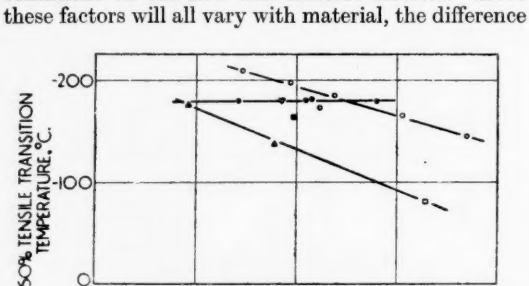
$$\log B = \log B_0 - bT$$

it can readily be shown that the difference between the Charpy and tensile transition temperatures is given by

$$T_{\text{Charpy}} - T_{\text{tensile}} = \log (K/k)/(a-b)$$

where K and k are the coefficients representing the effect of the conditions existing in the Charpy test on the static flow and fracture stresses, respectively, and a and b are the material constants representing the temperature coefficients of flow and fracture stresses, respectively.

In general, whatever the form of the stress/temperature relationships the difference between the transition temperatures for two different stressing conditions will be some function of the difference between the temperature dependence of the static flow stress and the temperature dependence of the static fracture stress, and the effects of the stress conditions on the flow and fracture stresses. Since these factors will all vary with material, the difference



Key as for Fig. 5

Fig. 9—Comparison of transition temperatures determined by tensile tests with transition temperatures determined by V-notch Charpy tests

between the tensile and impact transition temperatures will also in general vary with material. With materials between which these factors show some orderly relationship, as may well be the case for a series of steels of similar compositions and heat-treatments, a relationship between the transition temperatures may exist (*e.g.*, the carbon-steel results) but no general relationship can be expected. Hoyt[13] has suggested that, when choosing a material for a given structure, it is preferable to compare the materials by the stress conditions required to produce brittle fracture at the lowest operating temperature of the structure, rather than by comparison of impact transition temperatures. The present results support this conclusion, at least where the materials to be compared are of widely different composition and condition, or where the materials to be compared have impact transition temperatures very different from the required operating temperature.

It is therefore probable that the only satisfactory way of predicting the brittle fracture transition temperature for one set of conditions of loading from properties determined under other loading conditions is by consideration of the flow and fracture stress *v.* temperature curves. It was not possible to determine directly from the tensile results the fracture-stress/temperature curves for the steels, since the fracture stress was found to vary also with the amount of deformation preceding fracture, which itself varied with temperature. An approximate relationship for the variation of fracture stress with temperature was therefore found (*see* Fig. 10) using the results of

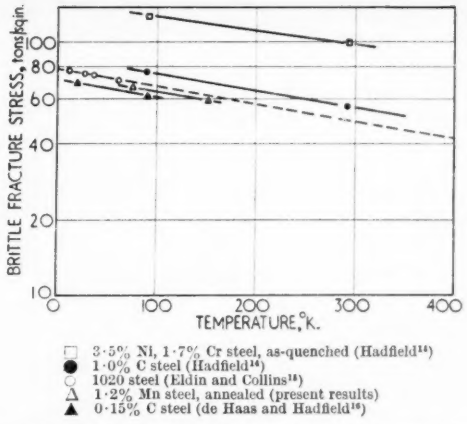


Fig. 10—Variation of brittle fracture stress with temperature

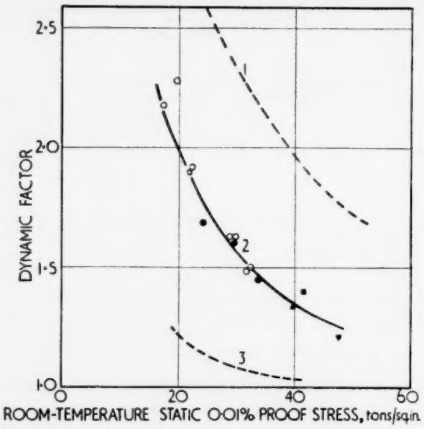
the two lowest-temperature tests on the 1·2% Mn steel in the annealed condition, which showed little deformation before fracture, together with results available in the literature.[14–16]

Applying this relationship ($\log B_T = \log B_0 - 0{\cdot}00068T$) for each steel to the stress for brittle fracture obtained from the tensile test results, the static fracture stress at a temperature corresponding to the Charpy mean transition temperature was determined. The ratio of this stress to the static 0·01% proof stress at the same temperature provided

Table II
COMPARISON OF VARIOUS BRITTLENESS CRITERIA

Material	Impact Properties						Tensile Properties									
	50% Cleavage Trans. Temp.		Upper Trans. Temp.		Maximum Energy Value		Red. in Area (Room Temp.)		Red. in Area (−197° C.)		Temp. for ½ Room Temp. Red. in Area		Elongation (Room Temp.)		Temp. of Elong. Drop	
	Value, °C.	Order of Brittleness	Value, °C.	Order	Value, ft.lb.	Order	Value, %	Order	Value, %	Order	Value, °C.	Order	Value, %	Order	Value, °C.	Order
0·15% carbon steel:																
As-rolled	− 54	13	− 30	13	133	14	68·0	14	47·7	15	< − 200*	15	36·8	14	− 140	10
Annealed	+ 23	6	+ 50	6	105	12	63·4	12	6·5	7	− 180	9	39·5	15	− 135	8
Q. and tempered	− 58	14	− 40	14	167	15	72·7	15	10·5	13	− 180	9	30·5	11	− 135	8
0·30% carbon steel:																
As-rolled	− 7	10	+ 20	12	81	11	58·0	10	16·0	14	− 193	14	32·0	12	− 150	13
Annealed	+ 38	5	+ 65	5	63	10	61·2	11	2·0	3	− 178	8	36·5	13	− 130	6
Q. and tempered	+ 15	7	+ 30	11	123	13	66·3	13	9·5	11	− 185	12	25·5	9	− 140	10
0·55% carbon steel:																
Q. and tempered	+ 96	4	+ 140	4	58	9	51·1	7	3·5	5	− 168	5	23·0	6	− 120	2
0·70% carbon steel:																
As-rolled	+ 105	3	+ 160	2	29	2	39·0	2	0·8	2	− 165	4	18·5	3	− 140	10
Annealed	+ 150	1	+ 200	1	22	1	50·7	6	3·0	4	− 145	3	26·0	10	− 120	2
Q. and tempered	+ 9	8	+ 50	6	42	7	47·4	4	4·5	6	− 180	9	17·8	1	− 130	6
0·6% C, 1·2% Mn steel:																
Annealed	+ 128*	2	+ 160*	3	35*	4	30·4	1	0·5	1	− 80	1	20·5	4	− 40	1
Q. and tempered	− 1	9	+ 40	9	34	3	54·8	8	9·5	11	− 175	6	25·0	8	− 120	2
3% Ni, 0·7% Cr steel:																
Q. and tempered	− 15	11	+ 50	6	36	5	43·2	3	9·2	10	− 185	12	18·0	2	− 150	13
0·4% C, 5% Ni steel:																
Annealed	− 22	12	+ 40	9	37	6	49·2	5	6·5	7	− 138	2	22·5	5	− 120	2
Q. and tempered	− 108	15	− 70	15	44	8	57·5	9	8·0	9	− 177	7	24·0	7	− 150	13

*Results obtained by extrapolation.



1. Experimental curve at strain rate 10^4 per sec. (Whiffin[18])
2. Factors calculated from present tensile results at transition temperatures determined by Charpy tests (strain rate 100–600 per sec.)
3. Experimental curve at strain rate 1 per sec. (Brown and Edmonds[17])

Key as for Fig. 5

Fig. 11—Variation of dynamic factor with static proof stress

the dynamic factor for the steel, and the values obtained are shown in Fig. 11. Assuming that the fracture stress under given conditions of loading is equal to the flow stress under those conditions at the transition temperature, these dynamic factors indicate the relative increase in flow and fracture stresses produced by the triaxiality, strain rate, and size effect in the **V**-notch Charpy tests at the mean transition temperature. The dynamic factors thus determined were found to decrease with increasing static proof stress and the results (which apply to a strain rate of between 100 and 500 per sec.) were intermediate between the dynamic-static yield-point ratios determined by Brown and Edmonds[17] at a strain rate of about 1 per sec. and those determined by Whiffin[18] at a strain rate of about 10^4 per sec. This indicates the possibility of estimation of the approximate brittle temperature for a structure, provided that the dynamic factor for the structure and the tensile properties of the material over a range of temperatures are known.

CONCLUSIONS

The tensile and impact properties of a series of carbon steels in the as-rolled, furnace-cooled, and quenched and tempered conditions were determined at several temperatures between + 200° and −197° C. Similar tests were also made on three alloy steels and two non-ferrous alloys.

The Young's modulus of each of these materials was found to increase linearly as the temperature of test decreased, the average coefficient of temperature change for the carbon steels being $-23{\cdot}1 \times 10^{-5}$ per °C. The proof-stress values for the carbon steels increased markedly as the test temperature decreased, especially at the lower temperatures, the variation with temperature showing some agreement with that predicted by dislocation theory. The increase in proof stress shown by the tests at −197° C. was greater for the steels which had the lower room-temperature proof-stress values. For many of the steels tested the drop in stress and amount of elongation at the yield point increased as the test temperature decreased, as did the proof-stress/ultimate-stress ratio and the ultimate stress. The breaking-stress values showed maxima at the temperatures at which maximum elongation occurred.

The tensile and impact properties were compared and it was found that of the former properties, the reduction in area values showed the closest agreement with the impact energy absorption in their general trend with decrease in temperature. The temperature at which the reduction in area showed a marked decrease varied between the steels, but this variation was less than that of the impact transition temperatures, nor did these two criteria classify the steels in the same order of brittleness. The absence of any general correlation between tensile transition temperature and impact transition temperature was explained in terms of flow-stress/temperature and fracture-stress/temperature relationships. Dynamic factors for the impact tests were calculated from the tensile properties using these concepts and the results showed reasonable agreement with experiment.

Acknowledgments

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Solubility of Nitrogen in Alpha-Iron

By J. D. Fast and M. B. Verrijp

SYNOPSIS

The internal friction of fine-grained textureless α-iron wires caused by nitrogen is shown to be proportional to the nitrogen content up to a concentration corresponding to the solubility at the eutectoid temperature (0·095 wt.-% at 585° C.). Making use of this fact the solubilities of nitrogen in α-iron in equilibrium with 'Fe_8N,' Fe_4N, and N_2 of 1 atm., respectively, are measured and shown to be given by the equations

$$q(\text{`}Fe_8N\text{'}) = 3{\cdot}3 \times 10^2\, e^{-9900/RT} \text{ wt.-\% N}$$

$$q(Fe_4N) = 12{\cdot}3\, e^{-8300/RT} \text{ wt.-\% N}$$

$$q(N_2\ 1 \text{ atm.}) = 9{\cdot}8 \times 10^{-2}\, e^{-7200/RT} \text{ wt.-\% N}$$

From the last two equations the dissociation pressures of Fe_4N are calculated to be given by

$$p_{N_2}(Fe_4N) = 1{\cdot}6 \times 10^4\, e^{-2200/RT} \text{ atm.}$$

in fairly good agreement with measurements of Emmett *et al.* 1100

Introduction

IN DISCUSSING THE SOLUBILITY of nitrogen in α-iron, a distinction must be made between the case where the metal is in equilibrium with an iron nitride, Fe_4N or 'Fe_8N,' and the case where only gaseous nitrogen, N_2, is present as a second phase. The solubility of nitrogen in α-iron in equilibrium with Fe_4N has been studied by several investigators, though with widely divergent results. The solubility of nitrogen in α-iron in equilibrium with N_2 has been determined only by Sieverts and his collaborators. Table I gives the results of measurements on solubility as found in the literature. The best values of solubility in equilibrium with Fe_4N are those of Dijkstra, deduced from measurements of the internal friction of nitrogen-containing α-iron, and those of Borelius and his collaborators, based on their method of isothermal calorimetry.

During his measurements Dijkstra[5] discovered the existence of a new iron nitride. At temperatures below about 300° C. it is formed as an intermediate in the separation of a supersaturated Fe–N solution into saturated α and Fe_4N. Later it was found by Jack[9] that the same phase is formed as an intermediate in the low-temperature decomposition of nitrogen martensite. In equilibrium with α-iron the new nitride is less stable than Fe_4N and as a consequence the solubility of nitrogen in α-iron in equilibrium with the new phase is greater than the corresponding solubility in equilibrium with Fe_4N. X-ray examination by Jack showed the new phase to be body-centred tetragonal with a structural unit containing eight ($2 \times 2 \times 2$) distorted and expanded body-centred units of the original supersaturated solution or martensite structure. The dimensions of the unit cell are

$$a = 5{\cdot}72 \text{ Å.},\ c = 6{\cdot}29 \text{ Å.};\ c/a = 1{\cdot}10.$$

It contains at the most two nitrogen atoms at 0, 0, $\frac{1}{4}$, and $\frac{1}{2}, \frac{1}{2}, \frac{3}{4}$. For convenience this phase may therefore be designated as 'Fe_8N,' but up to one-half the number of nitrogen atom sites may be vacant. The new phase is essentially a nitrogen-martensite, in which the nitrogen atoms are ordered.

Since the iron atoms in 'Fe_8N' have the same arrangement as in α-iron, formation of its nuclei demands a much smaller activation energy than the formation of Fe_4N nuclei, in which the iron atoms have the face-centred arrangement of γ-iron. If the temperature is relatively low (below 250° C.) and if the α-iron is supersaturated with respect to both Fe_4N and 'Fe_8N,' precipitation starts with the formation and growth of 'Fe_8N' nuclei. After a much longer time the more stable Fe_4N nuclei appear and grow at the expense of the first-formed precipitate. At higher temperatures (above 300° C.) thermal agitation of the atoms is so great that Fe_4N nuclei form without much delay.

In a recent note Åström and Borelius[10] report on new measurements of the solubility of nitrogen in α-iron in equilibrium with Fe_4N and 'Fe_8N.' From measurements of the elastic after-effect caused by nitrogen they deduce that the relaxation strength is not proportional to the quantity of dissolved nitrogen (*see* their Fig. 1). In contrast with this conclusion the damping theory of Snoek[11] and Polder[12] predicts proportionality between relaxation strength and nitrogen (or carbon) content for contents so small that interaction between interstitially dissolved atoms may be neglected (*see* formula (2)). Dijkstra[13] substantiated this prediction experimentally for dilute solutions of carbon in α-iron.

In this paper the results of an investigation are given, in which both the relation between quantity of dissolved nitrogen and internal friction and the solubilities of nitrogen in α-iron in equilibrium with N_2, Fe_4N, and 'Fe_8N' were determined. From the measured solubilities in equilibrium with N_2 and Fe_4N, dissociation pressures of Fe_4N are calculated and compared with those determined by other investigators.

SPECIMENS AND APPARATUS

Iron was obtained in very pure state by high-frequency melting and casting in a good vacuum.[14] The cast rods had diameters of 14 mm. and were transformed into 0·7-mm. dia. wire by cold swaging and cold drawing. Nitrogen was introduced into

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240-mm. lengths of the iron wire by heating them for varying times at 950° C. in a gas stream of the composition 99 vol.-% N_2 + 1 vol.-% H_2, if nitrogen contents smaller than about 0·026 wt.-% were wanted, and at 570° C. in mixtures of NH_3 + H_2 of varying compositions if greater contents were needed. The gases were purified according to normal practice. The carbon content of all wires used in the experiments was so small that it could not be detected by chemical analysis or internal friction measurements.

After varying heat-treatments, described below, the internal friction of the wires was measured at different temperatures between −20° and 60° C. For this purpose they were used as the suspension element in a torsional pendulum system with a period of oscillation of 1·13 sec. The logarithmic decrement was determined during free decay of the torsional oscillations. The loss angle β (often represented by the symbol Q^{-1} by analogy with electrical circuits) is found by dividing the logarithmic decrement by π. The apparatus used differed little from that described by Kê.[15]

DEPENDENCE OF INTERNAL FRICTION ON METHOD OF STRESSING AND CRYSTAL ORIENTATION

The magnitude of the internal friction of polycrystalline iron wires at a certain frequency and a certain temperature depends not only on the concentration of dissolved nitrogen (or carbon), but also on the dimensions and orientations of the crystals and on the way of periodically stressing them.

The internal friction of a single α-iron crystal containing dissolved nitrogen (carbon) and subjected to a periodically varying uniaxial stress is strongly dependent on the direction of the stress with regard to the crystallographic axes of the specimen. The formula giving this dependence was derived by Polder[12] and experimentally substantiated by Dijkstra.[13] It reads

$$Q^{-1} = \Delta \cdot \frac{\omega\tau}{1 + \omega^2\tau^2} \quad \ldots\ldots(1)$$

with

$$\Delta = \frac{2}{9}\frac{EV}{RT}C\left(\frac{e_{zz} - e_{xx}}{c_z}\right)^2\left\{1 - 3(\alpha_1^2\alpha_2^2 + \alpha_2^2\alpha_3^2 + \alpha_3^2\alpha_1^2)\right\} \quad \ldots(2)$$

where

Δ = relaxation strength
ω = angular frequency of mechanical oscillation
τ = relaxation time
$\alpha_1, \alpha_2, \alpha_3$ = direction cosines of stress with respect to cubic axes of crystal
E = modulus of elasticity in direction α_1, α_2, α_3
V = volume of one gramme atom (mole) of α-iron
R = gas constant per mole
T = absolute temperature
C = number of gramme atoms of nitrogen or carbon per gramme atom of iron
$(e_{zz} - e_{xx})/c_z$ = tetragonality factor, where
$e_{zz}(e_{xx})$ = relative deformation in the $z(x)$ direction of an α-iron crystal caused by c_z gramme atoms N(C) per gramme atom Fe, if the N(C) atoms are located exclusively at the z sites of the crystal ($c_x = c_y = 0$).

An analogous formula can be derived for a single crystal subjected to a periodically varying torsional stress. For the polycrystalline iron wires used in the present investigation, however, no exact theoretical computation of the magnitude of the internal friction is possible. An averaging procedure has in this case to be applied in order to derive the internal friction

Table I

SOLUBILITY OF NITROGEN IN α-IRON ACCORDING TO SEVERAL INVESTIGATORS, wt.-%

Temp., °C.	In Equilibrium with								
	Fe_4N								N_2 of 1 atm.
	Fry[1]	Eisenhut and Kaupp[3]	Séférian[2]	Köster[4]	Dijkstra[5]	Borelius, Berglund, and Avsan[6]	Åström and Borelius[10]	Paranjpe, Cohen, Bever, and Floe[9]	Sieverts, Zapf, and Moritz[7]
890									0·002
750									0·0004
590	0·5	0·42	0·13					0·10	
575					0·075	0·097			
550			0·05					0·070	
500	0·2				0·050		(0·062)		
450		0·32			0·035	0·059	0·047	0·033	
400	0·08			0·02	0·025	0·043	0·034		
350					0·015		0·024		
330						0·026	0·020		
300				0·01	0·010	0·018	0·015		
250					0·005		0·009		
240						0·014			
200				0·005	0·003	0·008			
100				0·001					

from the known orientation-dependent effect in a single crystal. The averaging may be carried out according to the 'uniform strain' hypothesis or the 'uniform stress' hypothesis. Different results are obtained and it is difficult to decide which way of averaging is the better. A third way of averaging,[16] depending on a semi-empirical argument (viz. on the observed relation between the elastic constants of single crystals and polycrystalline specimens of a number of cubic metals) yields probably the most reliable results. However, the only fully reliable way of deriving the relation between internal friction and nitrogen content for polycrystalline α-iron wires seems to be the experimental one.

Experiments showed that reproducible results could only be obtained if the dimensions of the crystals are small compared with the diameter of the wire and if they have random orientations. If the cold-drawn iron wire is recrystallized below the transformation point $\alpha \rightarrow \gamma$, it shows a texture on X-ray examination. In accordance with earlier work[17] the crystals were found to show preference for lying with a [110] axis parallel to the wire axis. The scatter about this direction was very large and not always the same. As a result different damping curves could be obtained for the same quantity of dissolved nitrogen and the same grain size.

Polycrystalline iron wires showing no preferred orientations could be obtained by recrystallizing the cold-drawn wire at 950° C., i.e. above the transformation point $\alpha \rightarrow \gamma$. If this recrystallizing was done in a high vacuum, crystals with diameters of the order of magnitude of the wire diameter were obtained. This large grain size proved to be another cause of irreproducible internal friction after subsequent introduction of nitrogen.

Wire with small, randomly orientated crystals having diameters about one-tenth of the wire diameter and giving reproducible results could be obtained by heating the cold-drawn wire for 20 min. or more at 950° C. in a gas stream of the composition 99 vol.-% N_2 + 1 vol.-% H_2. The quantity of nitrogen taken up during this heating could be varied up to a concentration of about 0·026 wt.-% by varying the time of heating. The content could be further raised without altering the crystal dimensions, by subsequent heating at 570° C. in mixtures of $NH_3 + H_2$ or lowered by heating in wet or dry hydrogen.[18]

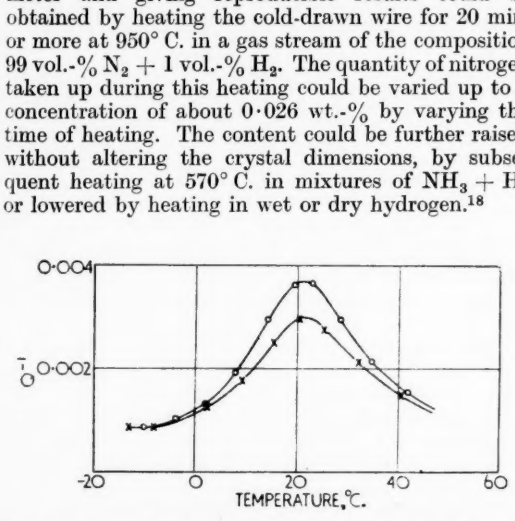

Fig. 1—Internal friction as function of temperature of two iron wires brought into equilibrium with nitrogen of 1 atm. at 835° C. The lower curve relates to a wire showing a [110] texture, the upper curve to a wire with randomly orientated crystals

As expected,[16] wires with random crystal orientations subjected to torsional oscillations showed a greater internal friction for the same nitrogen content than wires with a [110] texture. This is demonstrated by Fig. 1, showing the damping curves of two iron wires brought into equilibrium with nitrogen of 1 atm. (+ 1 % H_2) at 835° C. and subsequently quenched in water. The upper curve relates to a wire with small randomly orientated crystals, the lower curve to a wire that was never heated above the transformation point after cold-working and showed a [110] texture. The grain size of both wires was about the same. In all further experiments wires with small, randomly orientated crystals were used.

DEPENDENCE OF INTERNAL FRICTION ON NITROGEN CONTENT

To find the dependence of internal friction in torsional oscillations on nitrogen content, this friction was determined for two widely divergent nitrogen contents.

In a first series of experiments several wires were heated at 950° C. in a gas stream of the composition 99 vol.-% N_2 + 1 vol.-% H_2. After varying times the wires were quenched in water, heated for 10 min. at 570° C. in pure nitrogen, and again quenched in water. The height of the damping peak measured after the last quench increased initially with increasing time of heating at 950° C., but after 2–3 hr. a constant value was reached. Ten peak heights measured after 3, 4, and 8 hr. were all found to lie in the range

$$Q^{-1}_{\text{max.}} = 0{\cdot}0210 \pm 0{\cdot}0005.$$

These and all other values to be given in this paper are corrected for the relatively small background damping. The nitrogen contents of the wires were determined by the micro-Kjeldahl method and found to lie in the range

$$\text{wt.-\% N} = 0{\cdot}0265 \pm 0{\cdot}0010\,\%.$$

These values are to be compared with those of the solubility of nitrogen of 1 atm. in γ-iron at 950° C., determined by other investigators. Sieverts and his collaborators[19, 7] found widely divergent values at the temperature and pressure mentioned. Their values lie between 0·021% and 0·027% (*see* Fig. 1 of Sieverts' paper[19]). They consider their highest values to be the most reliable ones. Darken, Smith, and Filer[20] found a solubility of 0·026%, in perfect agreement with the present results.

In a second series of experiments the internal friction of wires with a much greater nitrogen content was determined. Wires loaded with 0·026% nitrogen in the manner described were heated for 2 hr. at 570° C. in a mixture of 91 vol.-% H_2 + 9 vol.-% NH_3. After quenching in water the peak heights were all found to lie in the range

$$Q^{-1}_{\text{max.}} = 0{\cdot}0585 \pm 0{\cdot}0008.$$

The Kjeldahl analyses of these wires gave

$$\text{wt.-\% N} = 0{\cdot}074 \pm 0{\cdot}001.$$

The results show that for torsional oscillations of

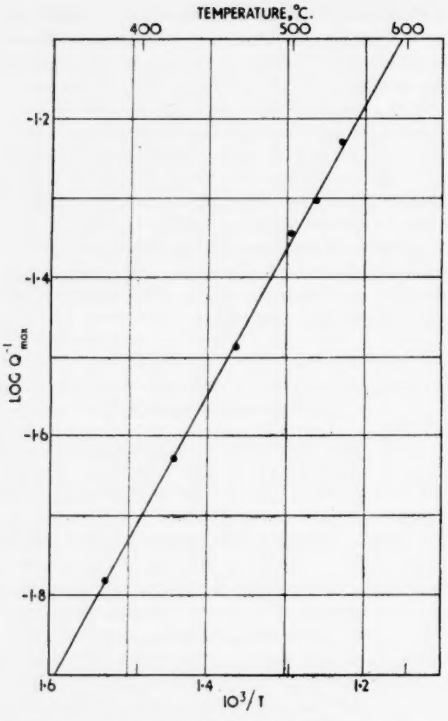

Fig. 2—Logarithm of peak height at 22° C., corresponding to solubility of Fe_4N in α-iron, plotted against 1/T

fine-grained textureless iron wires containing nitrogen the relation

$$\text{wt.-\% N} = 1{\cdot}26 \pm 0{\cdot}04\, Q^{-1}_{\text{max.}} \quad \ldots\ldots\ldots\ldots (3)$$

is valid in the whole region of interest, if the period of oscillation is such that the maximum of the internal friction curve lies at about 22° C. Relation (3) is in fair agreement with that derived semi-empirically by Smit and van Bueren[16] making use of the known tetragonality of nitrogen martensite. For the present authors' coefficient $1{\cdot}26 \pm 0{\cdot}04$ they find a value $1{\cdot}3 \pm 0{\cdot}1$, their accuracy being relatively low owing to the uncertainty of the tetragonality figures.

As mentioned in the introduction, Åström and Borelius[10] deduce from their measurements that, contrary to the present results, the relaxation strength is *not* proportional to the quantity of dissolved nitrogen. According to Åström and Borelius's Fig. 2, the maximum solubility of nitrogen in α-iron at the eutectoid temperature of 585° C. is 0·1 wt.-%. According to their Fig. 1 this would mean that an iron wire containing nitrogen can never show an internal friction peak higher than $Q^{-1}_{\text{max.}} = \varepsilon''/2\varepsilon' \simeq 0{\cdot}055$ at −18° C. after quenching from 580° C. The present experiments show that values of $Q^{-1}_{\text{max.}}$ higher than 0·070 can easily be obtained at room temperature by quenching iron wires containing 0·1% nitrogen from 580° C. Still higher values can be obtained by measuring at lower temperatures.[18] This means that at least one of Åström and Borelius's curves, the solubility or the relaxation strength curve, is incorrect.

The rate of precipitation increases very fast with increasing nitrogen content and the deviation from proportionality between $Q^{-1}_{\text{max.}}$ and % N found by Åström and Borelius is exactly the deviation to be expected if part of the nitrogen has already precipitated before the internal friction can be measured. The present authors were not able to get reproducible results with nitrogen contents greater than 0·08%. With nitrogen contents between 0·05% and 0·08% reproducible results could only be obtained by measuring very quickly a small number of points of the internal friction curve situated at both sides of the top. With nitrogen contents lower than about 0·03 wt.-% precipitation was so slow that no special precautions were necessary to prevent the formation of nitride in the specimens during the measurements of internal friction.

SOLUBILITY OF NITROGEN IN α-IRON IN EQUILIBRIUM WITH Fe_4N

In measuring the solubility of nitrogen in α-iron in equilibrium with Fe_4N, values that are too high may be obtained, e.g. by the presence of very finely divided Fe_4N or by the presence of 'Fe_8N'; the solution may even be supersaturated with regard to 'Fe_8N.' On the other hand, values that are too low may be obtained owing to the presence of lattice faults, especially dislocations.

Experiments with wires containing about 0·08% nitrogen showed that all errors are reduced to a minimum and reproducible results are obtained, if solubility measurements are carried out between 380° and 580° C., and if before these measurements are made the wires are very slowly cooled from 580° C. After the slow cooling the wires were heated at a constant temperature in the range mentioned above, the heating being continued until a constant height of the damping peak was obtained after quenching in water.

Figure 2 gives the logarithm of the peak height (maximum value of Q^{-1}) as a function of the reciprocal of absolute quenching temperature. From the straight line through the points and relation (3) the solubility of nitrogen in α-iron in equilibrium with Fe_4N is found to be given by

$$q(Fe_4N) = 12{\cdot}3\, e^{-8300/RT}\ \text{wt.-\% N} \quad \ldots\ldots\ldots (4)$$

Within the limits of experimental error the solubility values proved to be independent of the excess of nitrogen in the iron and thus of the amount of precipitate.

Equation (4) gives a maximum value (at the eutectoid temperature) for the solubility of nitrogen in α-iron in equilibrium with Fe_4N of 0·095 wt.-%. This value agrees very well with those obtained by Borelius, Berglund, and Avsan[6] (0·10%), by Åström and Borelius[10] (0·10%), and by Paranjpe, Cohen, Bever, and Floe[8] (0·10%). There is somewhat less agreement with the values as given by Séférian[3] (0·13%), and as extrapolated from Dijkstra's[5] measurements (0·08%). The main difference between the results of these authors and the present results lies in the dependence of solubility on temperature, the heat of

solution being 8300 cal./g. atom N in the present case as compared with 5330 cal. (Borelius, Berglund, and Avsan[6]), 6200 cal. (Åström and Borelius[10]), and 7700 cal. (Dijkstra[5]). We suppose that at low temperatures too high values were found by these authors owing to one or more of the causes mentioned in the first paragraph of this section. Paranjpe *et al.*[8] and Séférian[3] give insufficient measuring points to derive a heat of solution from their values.

Based on their non-linear experimental relation between relaxation strength and nitrogen content (their Fig. 1), Åström and Borelius[10] 'correct' the solubility values given by Dijkstra.[5] The present authors believe that the agreement constructed in this way between Dijkstra's values and those obtained by Åström and Borelius has little cogency because in their correction Åström and Borelius start from a solubility curve, ascribed to Dijkstra, corresponding to the relation $q(Fe_4N) = 1{\cdot}0\ e^{-4900/RT}$, whereas Dijkstra himself gives a curve corresponding to the equation $q(Fe_4N) = 7{\cdot}5\ e^{-7700/RT}$.

SOLUBILITY OF NITROGEN IN α-IRON IN EQUILIBRIUM WITH N_2

The equilibrium between α-iron and Fe_4N could easily be studied below 600° C. (*see* previous section) because equilibrium with the corresponding gas phase

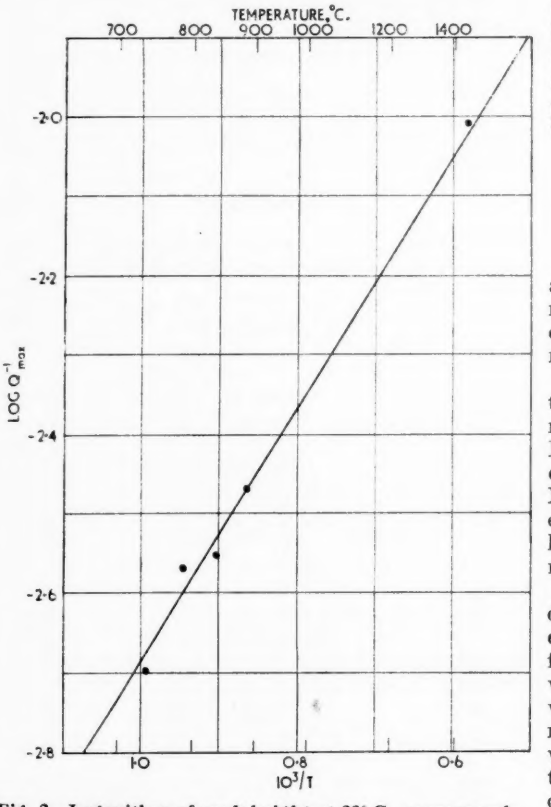

Fig. 3—Logarithm of peak height at 22° C., corresponding to solubility of N_2 of 1 atm. in α-iron, plotted against $1/T$

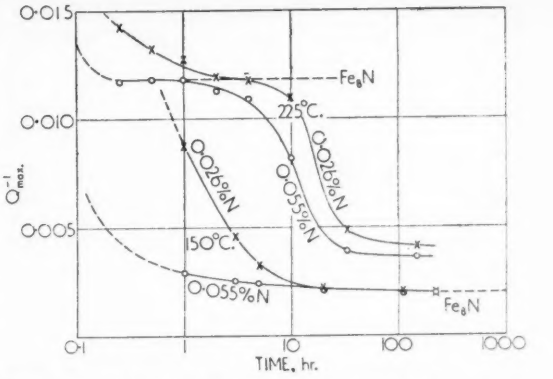

Fig. 4—Peak height at 22° C. as function of time of heating at 150° C. and 225° C. of two iron wires containing 0·055% and 0·026% N, respectively

(molecular nitrogen) does not become established in times available for the experiments. The energy barrier impeding attainment of this equilibrium is the activation energy of the surface reaction in which either molecular nitrogen is formed by recombination of the dissolved nitrogen atoms, or nitrogen is dissolved after dissociation at the iron surface. Loss of nitrogen by direct recombination does not occur at a perceptible rate. If, however, hydrogen is added to the gas phase, the adsorption layer on the iron surface contains hydrogen atoms in addition to nitrogen atoms and desorption of dissolved nitrogen can take place by a succession of surface reactions with relatively small activation energies:

$$N_{ads} + H_{ads} \rightarrow NH_{ads}$$
$$NH_{ads} + H_{ads} \rightarrow NH_{2ads}$$
$$NH_{2ads} + H_{ads} \rightarrow NH_{3gas}$$

The second reaction is the slowest of these at 500° C., according to Engelhardt and Wagner.[21] Even this reaction proceeds so fast at 500° C. and 600° C. that diffusion is rate-determining in the desorption of nitrogen from iron wires in hydrogen of 1 atm.[18]

The rate of *absorption* of nitrogen by α-iron, on the other hand, is always determined by the surface reaction, even in cases where the gas phase contains H_2 in addition to N_2. In pure N_2 no perceptible quantities are taken up by pure α-iron. In 99 vol.-% N_2 + 1 vol.-% H_2 and at temperatures above 700° C., equilibrium with the gas phase is established in several hours, but the surface reaction is still rate-determining.

Making use of the catalytic effect of hydrogen described above, solubilities of nitrogen in α-iron in equilibrium with N_2 of 1 atm. could be determined for a number of temperatures. Equilibrium values were reached 'from both sides' by starting with wires containing more and wires containing less nitrogen than the solubility values. (These wires were previously loaded with nitrogen at 950° C. in the manner already described, and subsequently deprived of part of their nitrogen by heating in hydrogen at 500° C.) Solubility values were considered reliable if the same final value was obtained in both

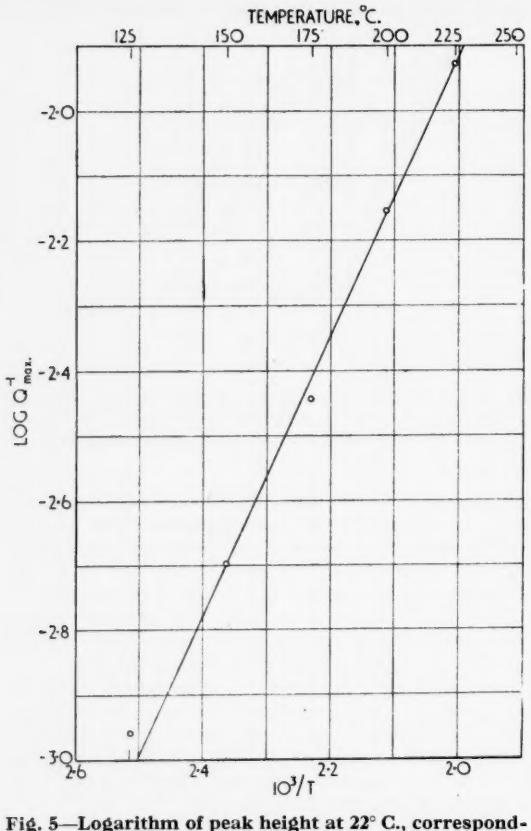

Fig. 5—Logarithm of peak height at 22° C., corresponding to solubility of ' Fe_8N ' in α-iron, plotted against 1/T

desorption and absorption experiments. Figure 3 gives the logarithm of the maximum value of Q^{-1}, measured after quenching in water, as a function of the reciprocal of absolute heating temperature. The value for 1450° C. was obtained by heating an iron wire by passage of electric current in 99 vol.-% N_2 + 1 vol.-% H_2. After interruption of the current the wire cooled in a few seconds to about 700° C. It was quenched in water from 570° C.

From Fig. 3 and relation (3) the solubility of nitrogen in α-iron in equilibrium with N_2 of 1 atm. is found to be given by

$$q\ (N_2;\ 1\ \text{atm.}) = 0{\cdot}098\ e^{-7200/RT}\ \text{wt.-\%\ N} \quad \ldots\ldots(5)$$

Equation (5) gives values for the solubility of nitrogen in δ-iron (stable between 1400° C. and 1540° C.) that agree fairly well with those determined by Sieverts, Zapf, and Moritz.[7]

SOLUBILITY OF NITROGEN IN α-IRON IN EQUILIBRIUM WITH ' Fe_8N '

The solubility of nitrogen in α-iron in equilibrium with ' Fe_8N ' was determined for five temperatures (125°, 150°, 175°, 200°, and 225° C.), using two iron wires containing 0·055 and 0·026 wt.-% nitrogen. After quenching from 570° C. the value of $Q^{-1}_{max.}$ (at 22·5° C.) was measured as a function of the time of heating at one of the five temperatures mentioned. The heating was continued until a seemingly constant value of $Q^{-1}_{max.}$ was reached. Figure 4 gives the results for a temperature of 150° C. As has been already shown by Djikstra[5] precipitation is seen to be much faster in the wire with the greater nitrogen content.

After a series of measurements as described above the wires were again quenched from 570° C. and the measurements repeated at one of the other five temperatures. Even after ten days' heating at 125°, 150°, and 175° C. there were no indications of a further drop of $Q^{-1}_{max.}$ corresponding to the formation of Fe_4N. On the other hand, at 200° and 225° C. such a second drop took place after a few hours. Figure 4 gives the results of the measurements for a temperature of 225° C. in addition to those for 150° C. The level of $Q^{-1}_{max.}$ corresponding to the solubility of ' Fe_8N ' is indicated in the diagram. The heating was not continued long enough to reach the equilibrium value of the solubility of Fe_4N. Even after 1000 hr. heating at 225° C. (or 200° C.) the value of $Q^{-1}_{max.}$ was still decreasing very slowly.

Figure 5 gives the logarithm of the values of $Q^{-1}_{max.}$ corresponding to the solubilities of ' Fe_8N ' as a function of the reciprocal of absolute temperature. From the straight line and relation (3) the solubility of nitrogen in α-iron in equilibrium with ' Fe_8N ' is found to be given by

$$q\ (\text{'}Fe_8N\text{'}) = 3{\cdot}3 \times 10^2\ e^{-9300/RT}\ \text{wt.-\%\ N} \quad \ldots\ldots(6)$$

Table II gives values of solubilities of nitrogen in α-iron in equilibrium with ' Fe_8N ', Fe_4N, and N_2 of 1 atm. as derived from equations (6), (4), and (5), respectively.

DISCUSSION

From equations (6), (4), and (5) it can be seen that the heats (enthalpies) of solution of the reactions

$$\text{'}Fe_8N\text{'} \rightleftharpoons 8\ Fe + [N] \quad \ldots\ldots(7)$$
$$Fe_4N \rightleftharpoons 4\ Fe + [N] \quad \ldots\ldots(8)$$
$$\tfrac{1}{2}\ N_2 \rightleftharpoons [N] \quad \ldots\ldots(9)$$

Table II

SOLUBILITIES OF NITROGEN IN α-IRON

In equilibrium with ' Fe_8N,' Fe_4N, and N_2 of 1 atm., respectively

Temp., °C.	In equil. with ' Fe_8N,' wt.-% N	In equil. with Fe_4N, wt.-% N	In equil. with N_2, 1 atm., wt.-% N
20	$1{\cdot}4 \times 10^{-5}$		
100	$5{\cdot}2 \times 10^{-4}$		
200	$8{\cdot}8 \times 10^{-3}$		
300	$5{\cdot}5 \times 10^{-2}$	$(8{\cdot}4 \times 10^{-3})$	
400	$(2{\cdot}0 \times 10^{-1})$	$2{\cdot}5 \times 10^{-2}$	
500		$5{\cdot}5 \times 10^{-2}$	$9{\cdot}0 \times 10^{-4}$
585		$9{\cdot}5 \times 10^{-2}$	$1{\cdot}4 \times 10^{-3}$
700			$2{\cdot}4 \times 10^{-3}$
800			$3{\cdot}3 \times 10^{-3}$
900			$4{\cdot}5 \times 10^{-3}$

where [N] indicates nitrogen dissolved in α-iron, are given by

$$\Delta H\ (7) = 9900 \text{ cal./g. atom N}$$
$$\Delta H\ (8) = 8300 \text{ cal./g. atom N}$$
$$\Delta H\ (9) = 7200 \text{ cal./g. atom N}$$

The possible error in ΔH (7) and ΔH (8) is estimated to be $\pm$ 200 cal./g. atom and in ΔH (9) $\pm$ 400 cal./g. atom.

Subtracting equation (9) from equation (8) gives the dissociation reaction

$$Fe_4N \rightleftharpoons 4\ Fe + \tfrac{1}{2}\ N_2 \quad \ldots\ldots(10)$$

with an enthalpy of dissociation

$$\Delta H\ (10) = 1100 \pm 600 \text{ cal./mol. } Fe_4N$$

In order to derive the dissociation pressures of Fe_4N equation (5) may be written in a more general form giving the solubility of nitrogen in α-iron in equilibrium with N_2 of p atm.:

$$q\ (N_2; p \text{ atm.}) = 0{\cdot}098\sqrt{p_{N_2}}\ e^{-7200/RT} \text{ wt.-\% N} \quad (11)$$

The dissociation pressures of Fe_4N (or strictly, fugacities of N_2 in equilibrium with this compound) are then immediately derived by combining equations (4) and (11):

$$p_{N_2}(Fe_4N) = 1{\cdot}6 \times 10^4\ e^{-2200/RT} \text{ atm.} \quad \ldots\ldots(12)$$

From quite different experiments (study of the catalytic activity of iron in NH_3 synthesis) Emmett, Hendricks, and Brunauer[22] found dissociation pressures which yield the relation

$$p_{N_2}(Fe_4N) = 2{\cdot}2 \times 10^4\ e^{-2300/RT} \text{ atm.} \quad \ldots\ldots(13)$$

In a way analogous to that of Emmett and his collaborators, Lehrer[23] found values yielding the relation

$$p_{N_2}(Fe_4N) = 10^6\ e^{-8050/RT} \text{ atm.}$$

It may safely be concluded that Lehrer's values (*see* his Fig. 7) are in serious error. For a temperature of 400° C. equations (12) and (13) give dissociation pressures of 3100 and 3900 atm., respectively.

It is rather surprising that the values of $Q^{-1}_{max.}$ corresponding to the solubility of Fe_4N in α-iron lie quite well on a straight line when plotting log $Q^{-1}_{max.}$ versus $1/T$ (Fig. 2). Guillaud and Creveaux[24] showed that Fe_4N is a ferromagnetic substance with a Curie temperature of 488° C. This means that below this temperature the internal energy of Fe_4N will show an abnormal decrease with decreasing temperatures. Consequently ΔH (8) should increase with decreasing temperatures and the log $Q^{-1}_{max.}/1/T$ line should be curved. The straight-line relationship of Fig. 2 could be understood if the magnetic energy of Fe_4N was either relatively small or spread out over a large range of temperatures. It could also be understood if the Curie temperature of Fe_4N was either much higher or much lower than 488° C. Bozorth[25] gives a value of 388° C., but this seems to be a misprint, as he refers to the work of Guillaud and Creveaux.[24]

An argument for a Curie temperature lower than about 400° C. could be the large entropy change of reaction

$$\text{'}Fe_8N\text{'} \rightleftharpoons Fe_4N + 4\ Fe \quad \ldots\ldots(14)$$

derived by subtracting equation (8) from equation (7). Equations (6) and (4) show that the entropy change is given by

$$\Delta S\ (14) = R \ln \frac{3{\cdot}3 \times 10^2}{12{\cdot}3} \simeq R \ln 27.$$

This large entropy change could be understood if it was assumed that 'Fe_8N' is below its Curie temperature in the temperature range of solubility measurements (125–225° C.), whereas Fe_4N is already above its Curie temperature in the range of solubility measurements (380–580° C.).

If this assumption is correct, then at low temperatures the enthalpy of solution of Fe_4N, ΔH (8), and the enthalpy of dissociation of Fe_4N, ΔH (10), will have larger values than those mentioned before, viz. 8300 and 1100 cal./mol., respectively.

The straight line obtained in plotting log $Q^{-1}_{max.}$ versus $1/T$ for 'Fe_8N' (Fig. 5) seems to indicate that the composition of this nitride does not change much with temperature when it is in equilibrium with α-iron. This need not be in contradiction with the results of Jack[9] as this investigator did not study equilibria.

Acknowledgment

The authors wish to express thanks to Dr. J. L. Meijering and to Ir. J. Smit for valuable discussions.

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The Effect of Alloying Elements on the Solubility of Nitrogen in Iron

PART I: THE SOLUBILITY OF NITROGEN IN PURE IRON AND IN 2·83% SILICON IRON

By N. S. Corney and E. T. Turkdogan

SYNOPSIS

The solubility of nitrogen in α-iron has been determined at various temperatures and nitrogen potentials. The nitrogen solubility in α-iron at 502° C., in equilibrium with iron nitride, was found to be 0·060% and at 605° C., in α-iron in equilibrium with (α + γ) iron, to be 0·100% nitrogen. It has been found that dissolved silicon (2·83%) reduces the solubility of nitrogen in α-iron, for example, from 0·0033% to 0·0019% at 900° C. under 1 atm. of nitrogen. It has also been shown that, in a 2·83% silicon–iron alloy, nitride formation does not occur above 705° C. under 1 atm. of nitrogen. The free-energy changes associated with the solution of nitrogen and the formation of iron nitride have been calculated. 1122

THERE IS AN INCREASING REALIZATION of the importance of nitrogen in steel, both in the dissolved and the combined state. Although considerable attention has been paid to its effect on strain-ageing and magnetic properties, there is little information available on the thermodynamics of nitrogen dissolved in iron and its alloys. Pearson and Ende[1] have collected the available data on some nitrides and presented them in a convenient form. However, much experimental work is still needed to substantiate the applicability of their data to the problems of the steel industry.

It is the aim of the present work to investigate the conditions under which nitrides can be formed in solid iron alloys. The method employed throughout the work has been to bring samples of iron and an iron–silicon alloy into equilibrium with nitrogen or ammonia–hydrogen mixtures of known nitrogen potential and then determine the nitrogen content of the metal. From these results the relevant free-energy changes of various reactions may be calculated. The present paper deals with the pure iron–nitrogen system and with the effect of silicon on the solubility of nitrogen in iron.

EXPERIMENTAL

Apparatus

The previously purified gases, i.e. nitrogen (or ammonia) and hydrogen, were metered and mixed before passing into the furnace. The furnace assembly is shown in detail in Fig. 1, and was constructed so that the hot gases only came into contact with the sample or fused silica (Vitreosil), thereby reducing the thermal decomposition of ammonia, as recommended by Lehrer[2] and Paranjpe *et al.*[3] At a later stage of this work, the furnace assembly was slightly modified so that four such reaction tubes could be heated in the same furnace and each supplied independently with the required gas mixture. The sample, in the form of a roll of foil, rested on a silica boat so that on movement into the reaction zone the thermocouple sheath passed axially through the roll. The boat could be moved along the tube by the action of a magnet on a piece of soft iron sealed in glass and connected by a silica rod to the boat.

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Dr. Corney is with the Physical Chemistry Section of the Association's Chemistry Department, and Dr. Turkdogan is Head of the Section.

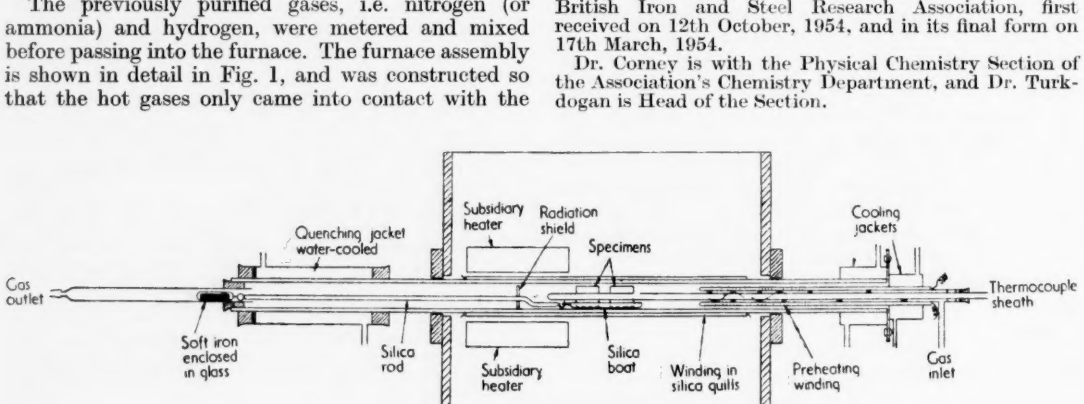

Fig. 1—The furnace assembly

The temperature of the furnace, which was automatically controlled to approximately $\pm 1{\cdot}0°$ C., was measured with a Pt/Pt–13% Rh thermocouple and Cambridge slide-wire potentiometer.

For the work at temperatures above 1000° C. a platinum-wound furnace was used with a recrystallized-alumina reaction tube. In these experiments a preheater for the inlet gas was not used. The samples were placed in an alumina boat which could be inserted into and removed from the hot zone by means of a stiff molybdenum tape passing through a simple seal at the end of the reaction tube. The temperature of the furnace could be maintained within a range of 5° C. about the required value.

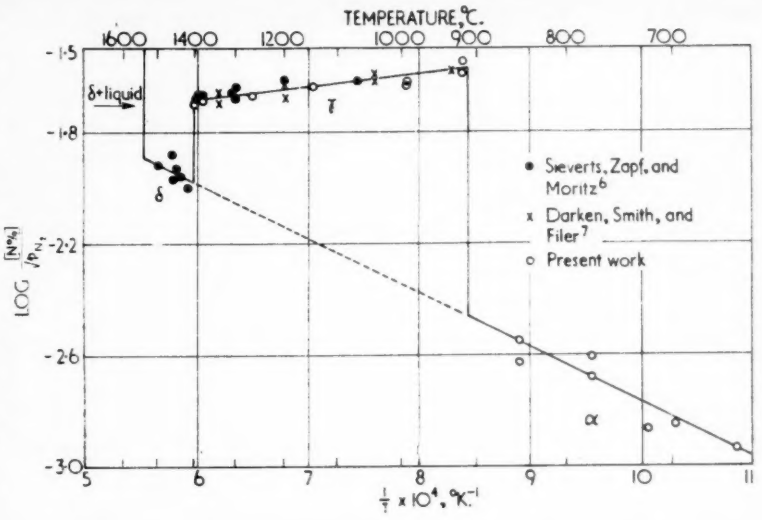

Fig. 2—The solubility of nitrogen in α-, γ-, and δ-iron in equilibrium with nitrogen at 1 atm.

Materials

B.I.S.R.A. *AH* iron was used in the form of foil approx. 0·002 in. thick.

The silicon–iron alloy was also B.I.S.R.A. material in the form of foil about 0·005 in. thick and had the following composition: 2·83% Si, 0·004% C, 0·001% N, 0·0087% S, 0·0005% O, and 0·003% Al. The *AH* iron contained 0·001% Si and the other impurities were of the same order as in the silicon iron.

Hydrogen — Oxygen-free hydrogen was passed through platinized asbestos at 350° C. and then through columns containing Sofnolite and anhydrous magnesium perchlorate.

Nitrogen—Oxygen-free nitrogen was passed through columns of Sofnolite and magnesium perchlorate, then over copper at 500° C., iron turnings at 900° C., and finally through anhydrous magnesium perchlorate.

Ammonia—Anhydrous ammonia (99·95%) was passed through a column of previously ignited calcium oxide.

Procedure

The metal samples were thoroughly cleaned with emery cloth and degreased by refluxing in carbon tetrachloride before use. After flushing the reaction chamber with nitrogen and then with the required gas mixture, the boat carrying two samples, each weighing about 1 g., was pushed into the furnace. During the experiment the temperature distribution along the furnace and flow rate were checked several times. When ammonia was used, gas samples were taken and analysed, usually soon after the experiment began and just before it finished. At the end of the experiment, the boat was withdrawn into the cold part of the reaction tube, thereby quenching the sample; after quenching, the reaction tube was again flushed with nitrogen before removing the sample.

The duration of each experiment was usually 24 hr. but occasionally it was extended to 48 or 72 hr. The preliminary results indicated that 24 hr. reaction time was long enough for the establishment of equilibrium for the solubility measurements.

For the solubility determinations, the samples have been brought into equilibrium with nitrogen containing 5% hydrogen in order to eliminate oxide formation. In the study of nitride formation, ammonia–hydrogen mixtures have been used; an increase in the ammonia concentration raises the amount of nitrogen dissolved in the metal up to the point where nitrogen in solution is in equilibrium with iron nitride.

In experiments with ammonia–hydrogen atmospheres, there is the risk of contamination of the metal with silicon produced from the reduction of the silica reaction tube. To determine the extent of this contamination, several samples of pure iron foil were annealed in hydrogen at 1000° C. for 24 hr. and silicon contents of the samples were found to be less than 0·004%. In subsequent experiments it was therefore assumed that the samples were not contaminated by silicon.

Analysis

The analysis for nitrogen in the metal was carried out by a micro-Kjeldahl method based upon that described by Beeghly[4]; the reproducibility of the results was approx. $\pm 0{\cdot}0005\%$.

When ammonia–hydrogen mixtures were used in nitriding pure iron, the outflowing gas was analysed to determine the extent to which thermal cracking of the ammonia had occurred. The analysis was carried out using a method similar to that described by Baldwin[5] by which ammonia was removed by condensation at −180° C. and then allowed to volatilize so that its pressure in a known volume could be measured. Hydrogen was oxidized by heated copper oxide and measured by difference. Nitrogen was determined as a residual gas. Close check between

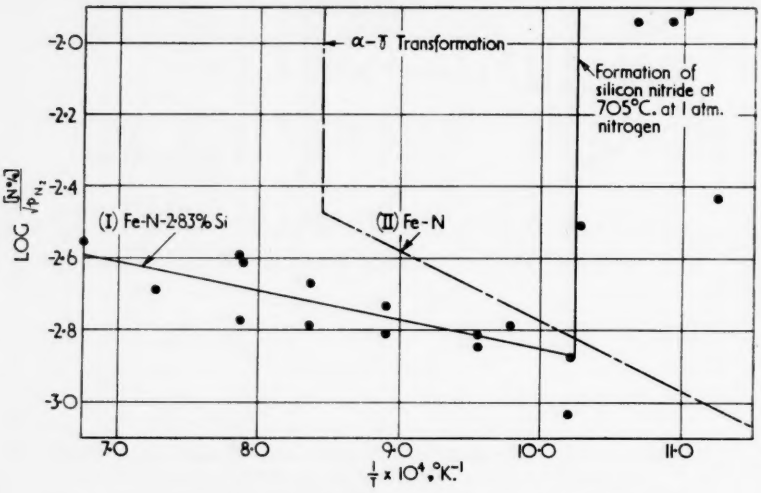

Fig. 3—The solubility of nitrogen in α-iron containing 2·83% Si, in equilibrium with nitrogen at 1 atm.

the composition of ingoing and outcoming gas indicated the virtual absence of thermal decomposition of ammonia, under the experimental conditions used.

RESULTS

Pure Iron

The solubility of nitrogen in pure iron has been determined over the temperature range 600–1400° C. The results obtained, together with those of previous workers, are shown in Fig. 2 in the form of a plot of $\log [N\%]/\sqrt{p_{N_2}}$ against $1/T$. The present work is in good agreement with the work of Sieverts, Zapf, and Moritz[6] and Darken, Smith, and Filer.[7] It is interesting to note that the points for nitrogen solubility in α- and δ-iron lie on one straight line, indicating that the heat of solution of nitrogen in δ-iron is the same as in α-iron, as would be expected.

The reaction studied may be represented by

$$\tfrac{1}{2}N_2(g) = [N] \quad \ldots\ldots (1)$$

and since, as shown in a following section, Henry's law is obeyed, the equilibrium constant may be written as follows:

$$K = \frac{[N\%]}{\sqrt{p_{N_2}}} \quad \ldots\ldots (2)$$

where p_{N_2} is in atmospheres. The temperature dependence of the equilibrium constant and the corresponding free-energy changes for solutions in α- and δ-iron or γ-iron may be calculated from the lines in Fig. 2.

(i) In α- and δ-iron for the temperature range 298–1083° K. and 1673–1808° K.

$$\log K_1 = -\frac{1980}{T} - 0{\cdot}795;\ \Delta G^\circ_1 = 9060 + 3{\cdot}637T$$
at 1% [N] activity.....(3)

(ii) In γ-iron for the temperature range 1083–1673° K.

$$\log K_2 = \frac{450}{T} - 1{\cdot}955;\ \Delta G^\circ_2 = -2060 + 8{\cdot}944T$$
at 1% [N] activity...(4)

α-Iron Containing 2·83% Silicon

This work was carried out using nitrogen–hydrogen mixtures as for pure iron. The results are shown in Fig. 3, where $[N\%]/\sqrt{p_{N_2}}$ is the 'equilibrium ratio' K'_1 of reaction (1) in the presence of 2·83% Si. Line (II) is the corresponding plot for the solution of nitrogen in pure α-iron. The best line (I) through the points in Fig. 3, obtained by the method of least squares, is given by

$$\log K'_1 = -\frac{814}{T} - 2{\cdot}037 \ldots (5)$$

The scatter of the points in Fig. 3 is within the limits of accuracy of determination of the very low nitrogen contents of the metal, which in no case exceeded 0·003%.

It may be noted that the nitrogen contents of the alloy below 705° C. are much higher than those above this temperature and they are distributed at random in Fig. 3. This behaviour is attributed to the formation of silicon nitride (which may also contain some iron nitride in solid solution) below this temperature, when 2·83% silicon–iron alloy is equilibrated with gaseous nitrogen at 1 atm.

Iron Nitride and Nitrogen Austenite Formation

At two temperatures the solubility measurements have been extended beyond the region attainable with nitrogen at atmospheric pressure by the use of ammonia/hydrogen mixtures. Figure 4 shows the results plotted in the form of the ratio $p_{NH_3}/(p_{H_2})^{\frac{3}{2}}$ (p is in atmospheres) against the nitrogen content of the iron, for the series of experiments at 502° and 605° C. At the lower temperature the plateau indicates the equilibrium of nitrogen ferrite with iron nitride. The random distribution of the points above the horizontal line is due to the fact that sufficient time has not been allowed for the complete conversion of the iron to iron nitride. The results at 605° C. are shown by line (II); at this temperature iron nitride does not form, and the plateau gives the ammonia/hydrogen ratio in equilibrium with the $(\alpha + \gamma)$ iron phases.

From Fig. 4 it can be seen that at 502° C. the solubility of nitrogen in α-iron in equilibrium with iron nitride is 0·060%, and at 605° C. the solubility of nitrogen in α-iron in equilibrium with γ-iron is 0·100%.

The linear relationships in Fig. 4 show that Henry's law, and hence Sieverts' law, is obeyed up to the limit of nitrogen solubility and it is therefore justified to use weight percentage of nitrogen instead of activity in the calculations quoted earlier.

Lehrer[2] and Emmett, Hendricks, and Brunauer[8] have equilibrated ammonia–hydrogen mixtures with pure iron at various temperatures, and, as indicated by the following table, the present results agree with those of the early workers:

Ammonia–Hydrogen Mixtures in Equilibrium with Nitrogen Ferrite and Iron Nitride Fe_4N

Temp., °C	$NH_3/(H_2)^{\frac{3}{2}}$, atm.
Present work	
502	0·282
605	0·119
Lehrer[2]	
480	0·311
503	0·280
512	0·264
597	0·145
604	0·145
Emmett, Hendricks, and Brunauer[8]	
444	0·512
460	0·472
525	0·226

DISCUSSION

Theoretical Considerations

The solubility of nitrogen in α-iron in equilibrium with iron nitride has been the subject of a number of investigations in recent years, notably by Paranjpe *et al.*,[3] Dijkstra,[9] and Borelius *et al.*[10] Moreover, Åström and Borelius[11] have reconsidered the experimental results on nitrogen solubility by the internal friction method,[9] and applied certain corrections to them. From the 'corrected' solubility *v.* $1/T$ relationship for the reaction

$$Fe_4N(\gamma') = 4Fe(\alpha) + [N(\alpha)] \quad \ldots\ldots(6)$$

the following free-energy change has been obtained

$$\Delta G^\circ_3 = 5720 - 1{\cdot}803T \text{ at } 1\% \text{ [N] activity} \quad \ldots\ldots(7)$$

Combination of reactions (1) and (6) and equations (3) and (7) yields

$$4Fe(\alpha) + \tfrac{1}{2}\,N_2(g) = Fe_4N(\gamma') \quad \ldots\ldots(8)$$

and

$$\Delta G^\circ_4 = 3340 + 5{\cdot}44T \quad \ldots\ldots(9)$$

The heat and entropy terms in the above expression differ very materially from those calculated by using the experimental results of Lehrer[2] and Emmett, Hendricks, and Brunauer[8] together with the free energy of formation of ammonia.[1] This comparison indicates that equation (7) based on the data corrected by Åström and Borelius[11] must be in error.

The original results of Dijkstra[9] and Paranjpe *et al.*[3] agree well with one another and from their data the free-energy change of reaction (6) is found to be

$$\Delta G^\circ_5 = 8330 - 4{\cdot}96T \text{ at } 1\% \text{ [N] activity} \quad \ldots(10)$$

(*see* Addendum for further evidence for the validity of this equation). At 502° C. the nitrogen in solution in equilibrium with Fe_4N is, according to equation (10), 0·055%, which compares favourably with the authors' result 0·060%. As indicated in the Appendix, calculations based on equation (10) give values concordant with the experimental results of other investigators.[2, 8] The free energy of formation of iron nitride (reaction 8) may now be recalculated by means of equations (3) and (10) to give

$$\Delta G^\circ_6 = 730 + 8{\cdot}60T \quad \ldots\ldots(11)$$

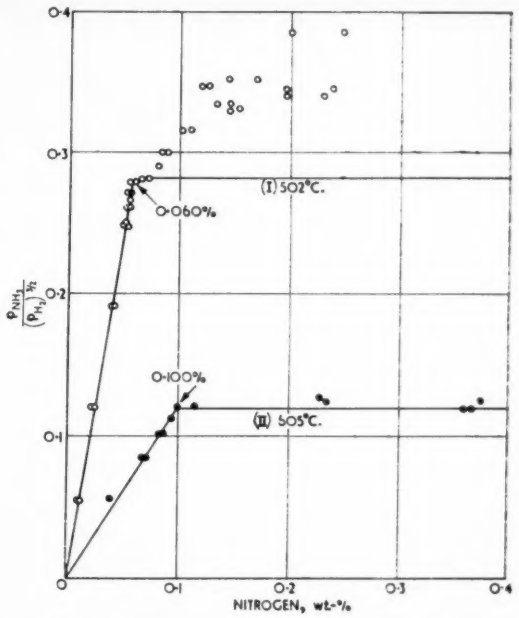

Fig. 4—The ratio $(p_{NH_3})/(p_{H_2})^{\frac{3}{2}}$ in atm. in equilibrium with the concentration of nitrogen dissolved in α-iron

Comparison of the lines in Fig. 3 indicates that addition of 2·83% silicon to iron reduces the solubility of nitrogen therein at a given temperature and nitrogen partial pressure. This behaviour is due to the effect of silicon in raising the activity coefficient of dissolved nitrogen. The value of this factor, i.e. f_N^{Si}, may be evaluated from the following equation

$$\log f_N^{Si} = \log K_1 - \log K'_1 \quad \ldots\ldots(12)$$

and by using equations (3) and (5) it follows that

$$\log f_N^{Si} = -\frac{1166}{T} + 1{\cdot}242 \quad \ldots\ldots(13)$$

at 2·83% silicon concentration.

Practical Considerations

From the metallurgical point of view, it is important to note that, as indicated by the present work, during heat-treatment of 2·83% silicon–iron alloy above 705° C. in nitrogen at 1 atm., silicon nitride will not be formed, but it may form subsequently when the metal is cooled. The theoretical considerations also indicate that if the silicon content of iron is reduced, the critical temperature, at which silicon nitride forms, is also reduced and *vice versa*. It must, however, be borne in mind that if slight traces of ammonia should be present in the annealing atmosphere, arising perhaps from the use of incompletely cracked ammonia, the critical temperature will be higher. The above statements refer to the equilibrium conditions only and take into account neither rate of diffusion of nitrogen in iron alloys nor the influence of surface conditions, and consequently nitrogen pick-up during annealing of steel, under industrial conditions, may

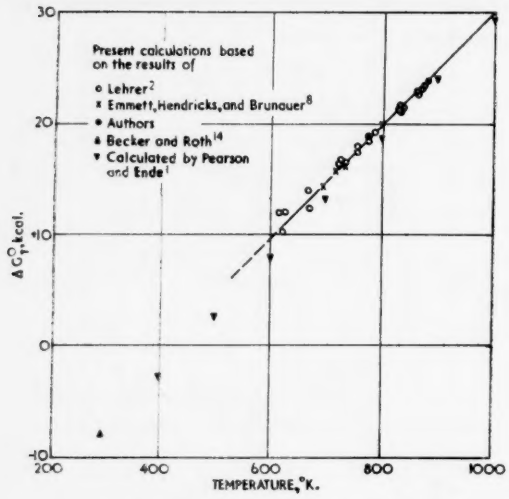

Fig. 5—The free-energy-change *v.* temperature relationship for the reaction $3H_2(g) + N_2(g) = 2NH_3(g)$

not be as much as might be expected from equilibrium considerations.

CONCLUSIONS

The free energies of solutions of nitrogen in solid iron are found to be

(i) $\frac{1}{2}\,N_2(g) = [N(\alpha, \delta)]$

$$\Delta G_T^\circ = 9060 + 3{\cdot}637T \text{ at } 1\%\ [N] \text{ activity.}$$

(ii) $\frac{1}{2}\,N_2(g) = [N(\gamma)]$

$$\Delta G_T^\circ = -2060 + 8{\cdot}944T \text{ at } 1\%\ [N] \text{ activity.}$$

Silicon reduces the solubility of nitrogen in α-iron and increases the activity coefficient of dissolved nitrogen to the extent given by the following equation

$$\log f_N^{Si} = -\frac{1166}{T} + 1{\cdot}242$$

at 2·83% silicon.

It has been shown that silicon nitride does not form in this alloy above 705° C. under 1 atm. of nitrogen. At lower silicon concentrations, this critical temperature is expected to be lower.

The present experimental results, together with other available data, give the following for the free energy of formation of iron nitride:

$$4Fe(\alpha) + \tfrac{1}{2}\,N_2(g) = Fe_4N(\gamma')$$

$$\Delta G_T^\circ = 730 + 8{\cdot}60T \text{ (from 298° to 868° K.)}$$

Acknowledgment

The authors wish to express their appreciation to Dr. J. Pearson for helpful discussions during the course of this work.

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APPENDIX

The Free Energy of Formation of Ammonia

As pointed out in the paper, Lehrer[2] and Emmett, Hendricks, and Brunauer[8] measured the composition of ammonia–hydrogen mixtures in equilibrium with nitrogen ferrite and iron nitride, Fe_4N. For the reaction

$$2Fe_4N(\gamma') + 3H_2(g) = 2NH_3(g) + 8Fe(\alpha) \quad \ldots\ldots(14)$$

the following free-energy change may be written

$$\Delta G_T^\circ = -RT \log [(p_{NH_3})^2/(p_{H_2})^3] \quad \ldots\ldots(15)$$

Combination of equation (15) evaluated from the above workers' results, with the free energy of formation of iron nitride given in equation (11), yields the free energy of formation of ammonia. The results of the calculations are given in Fig. 5. The value of ΔG° at 298·16° K. is obtained from the entropy change of the reaction, i.e. $\Delta S^\circ_{298} = -47{\cdot}47$ e.u. (Kelley[13]), and the heat of formation of ammonia determined by Becker and Roth,[14] i.e. $\Delta H^\circ_{298} = -11{\cdot}040$ cal./mole. The present calculations are in fair agreement with those based on the thermal data.[1] There appears to be a slight curvature in the $\Delta G_T^\circ/T$ relationship, and for the high-temperature range the following equation may be written for the reaction

$$3H_2(g) + N_2(g) = 2NH_3(g) \quad \ldots\ldots(16)$$

$$\Delta G^\circ_{600\text{–}1000°K.} = -21{,}250 + 51{\cdot}25T \pm 500 \text{ cal.} \quad \ldots(17)$$

ADDENDUM

At the time this work was completed, the authors became aware of the results of Fast and Verrijp (this issue, pp. 337–343), who investigated the solubility of nitrogen in iron by the internal friction method. They found the following free energy of solution of nitrogen in α-iron in equilibrium with iron nitride Fe_4N:

$$\Delta G_T^\circ = 8300 - 4{\cdot}99T \text{ at } 1\%\ [N] \text{ activity}$$

which is in complete agreement with that derived from the results of Dijkstra and Paranjpe *et al.*, i.e. equation (10).

The Solubility of Sulphur in Iron and Iron–Manganese Alloys

By E. T. Turkdogan, Ph.D., M.Met., S. Ignatowicz, Dipl.Ing., and J. Pearson, Ph.D., M.Sc., F.R.I.C.

SYNOPSIS

The solid solubility of sulphur in γ-iron has been determined at 1000°, 1200°, and 1335° C., and found to be 0·013%, 0·031%, and 0·046%, respectively. In the presence of 0·37%, 1·07%, and 1·30% of manganese the sulphur solubility is 0·0018%, 0·0007%, and 0·0006%, respectively, at 1200° C. In iron–manganese alloys containing 0·37%, 0·70%, and 1·30% of manganese, the solubility of sulphur at 1335° C. is 0·0058%, 0·0031%, and 0·0018%, respectively. The activity coefficient of dissolved sulphur is lowered to a measurable extent by manganese. These solubility changes and the nature of the sulphides formed when the solubility is exceeded indicate why manganese has a favourable influence on the hot workability of steel. 1116

IT HAS OFTEN been suggested that hot-shortness, which occurs during heat-treatment and hot working of steel, becomes more serious when the sulphur content of the steel is high. In practice it has been found that certain alloying elements, e.g. manganese, minimize the risk of hot-shortness and similar phenomena encountered in hot working. There is also evidence that overheating may be connected with the formation of sulphide precipitates. To clarify the part played by sulphur in causing these defects in steel, it was considered important to investigate the influence of alloying elements on the solid solubility of sulphur in iron. This paper deals with the effect of manganese.

EXPERIMENTS

Apparatus

In principle, experimental work involved the establishment of equilibrium between hydrogen-sulphide/hydrogen mixtures and metal samples at given temperatures followed by analysis of each sample for sulphur.

In these experiments the gas mixture was circulated in a closed system through two furnaces; one furnace contained ferrous sulphide at a known but variable temperature and the other held the metal sample at a known and fixed temperature. The sulphur partial pressure of the gas phase was controlled by the temperature of the sulphide furnace.

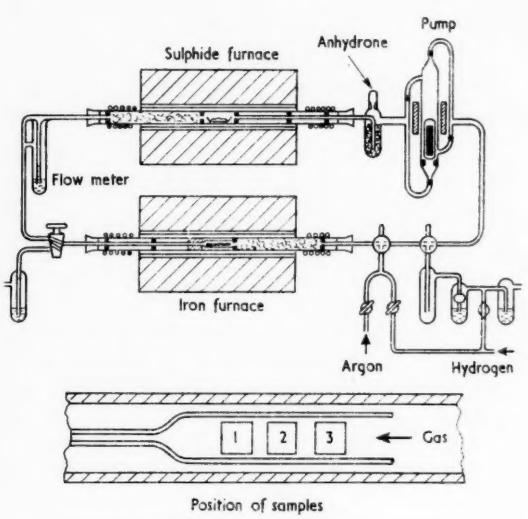

Fig. 1—Apparatus

The details of the apparatus are shown in Fig. 1. To avoid the contamination of the samples by silicon, through the reduction of silica by hydrogen, all the refractories employed within the reaction chamber were of pure recrystallized alumina. Temperature, measured by a Pt–Pt/13% Rh thermocouple, could be kept constant within ± 2° by the use of automatic temperature controllers, and along a length of 2 in. of the hot zone the temperature distribution was even.

The gas mixture in the system was circulated by means of an all-glass pump.[1] The average rate of gas flow used was about 120 ml./min. This flow rate together with the preheating arrangement, shown in Fig. 1, prevented thermal diffusion in the gases. Some experiments were carried out in which the hydrogen-sulphide/hydrogen mixtures contained 50% of argon, but the results obtained were the same as those in the absence of argon, indicating that the thermal segregation of the gases was already eliminated without the introduction of a heavy gas such as argon.

Materials

The materials used are detailed below.

Fe–FeS Mixture—High-purity ferric oxide placed in a recrystallized alumina crucible was reduced by pure hydrogen at 900–1000° C. The reduction was followed by the passage of dry, pure hydrogen sulphide which was generated by the action of a saturated aqueous solution of magnesium chloride on dry

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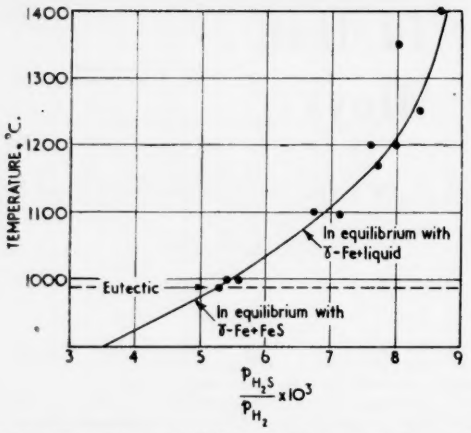

Fig. 2—Hydrogen-sulphide/hydrogen ratio in equilibrium with iron–sulphur melts along the γ-iron liquidus curve

calcium sulphide. The sulphur content of the sulphide produced was about 28–31%.

Pure Iron—The pure iron used in the present experiments was B.I.S.R.A. iron (code *AH*) of the following percentage composition:

C, 0·003 Si, 0·002 P, < 0·001 S, 0·004
Mn, 0·004 Ni, 0·005 Cr, 0·001 Cu, 0·005
Al, < 0·001 W, < 0·01

To ensure that the equilibrium would be established between the gas mixtures and sulphur dissolved in metal within a relatively short time, e.g. 12–24 hr., samples of large surface-area/bulk ratio were necessary. Satisfactory results were obtained with samples 0·002–0·004 in. thick.

Pure Iron–Manganese Alloys—Four iron–manganese alloys, containing 0·37%, 0·70%, 1·07%, and 1·30% of manganese, were manufactured by Johnson Matthey and Co. Ltd. and were supplied as ribbon, 0·002 in. thick and 1·5 in. wide. The purity of these alloys has been checked by spectrographic analysis and found, apart from the manganese content, to be similar to that of the *AH* iron.

Gases—' Oxygen-free ' hydrogen was purified from residual traces of oxygen over palladized asbestos at about 400° C., and dried by passage through a column of Anhydrone. Argon, which was used for flushing the reaction tube before the withdrawal of the sample, was originally purified by calcium chips at 600° C. Later, it was found that this purification was not necessary.

Procedure

The iron/iron-sulphide mixture was spread evenly in an alumina boat and placed inside the reaction tube of the sulphide furnace. Three metal samples, each weighing about 1·0 g., were put in an alumina thimble and placed in the hot zone of the other furnace, whilst a fast flow of argon was passing through the reaction tube.

Before each experiment the system was checked for leaks by filling it with hydrogen at a pressure higher than atmospheric and observing the constancy of the pressure by means of a dibutyl phthalate manometer.

Preliminary experiments, at 900° C. and for a fixed hydrogen-sulphide/hydrogen ratio, showed that equilibrium with respect to the dissolution of sulphur in iron was obtained within 15 hr.; increasing the reaction time to as long as 72 hr. did not increase the sulphur content of the sample. In the subsequent experiments the following procedure was adopted. At the end of the reaction period, the circulation of the gas was stopped, the iron furnace was isolated from the system, and the gas mixture in the reaction tube was swept out by argon; the samples were then pulled to the water-cooled zone of the tube and allowed to cool to room temperature in a fast stream of argon. During the operation the samples did not become oxidized.

The middle sample (2) (*see* Fig. 1) was always taken for analysis; the sample (1) was then placed in the middle position, the sample (3) in the position previously occupied by the sample (1), and a new sample was put to position (3). This technique was also used by Rosenqvist and Dunicz[2] and was found to give the most satisfactory results.

Determination of Sulphur in Metal Samples

Attempts to use the evolution method involving an alkaline solution of sodium hypochlorite[3] were unsuccessful. The determination of small amounts of sulphur, e.g. of the order of 10–100 μg., by the ordinary volumetric analysis technique necessitated the use of rather dilute solutions of hypochlorite, which were found to be unstable. This difficulty was remedied by the use of potassium iodate in a strong alkaline solution as oxidant. The details of this method of sulphur analysis will be reported elsewhere. The reproducibility and accuracy of the sulphur analysis was checked against solutions containing known quantities of sulphur and also against a standard steel. Reproducibility of the order of ± 0·00006% S could be obtained by using sufficiently dilute solutions for samples containing very low percentages of sulphur; when samples contained more than 0·01% of sulphur, the uncertainty of the analysis was of the order of ± 0·001% S but this was regarded as satisfactory for the purpose in hand.

RESULTS

Some time after this investigation was started Rosenqvist and Dunicz[2] published the results of their

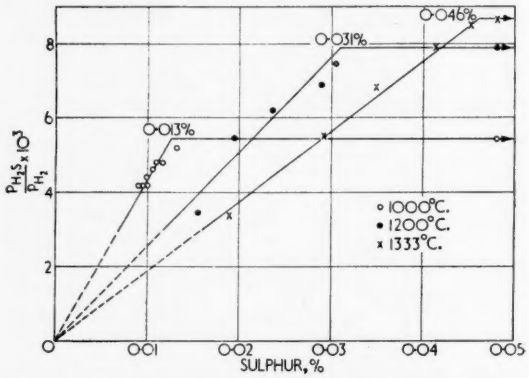

Fig. 3—Hydrogen-sulphide/hydrogen ratio related isothermally to the sulphur content of iron

work on the solubility of sulphur in solid iron. Since these authors had made a thorough investigation of the system, present experiments were limited to three temperatures only, and work was then extended to solid solubility of sulphur in iron–manganese alloys.

Unlike the experimental method employed by Rosenqvist and Dunicz, gas analysis was not required in the present experiments, because the sulphur pressure or hydrogen-sulphide/hydrogen ratio in the system could be calculated from reliable data on the free energy of formation of ferrous sulphide. For the temperature range 500–988° C. (eutectic temperature) Rosenqvist[4] found that the relationship

$$\log \frac{p_{H_2S}}{p_{H_2}} = -\frac{3100}{T} + 0{\cdot}179 \quad \ldots\ldots\ldots\ldots (1)$$

held for the reaction

$$FeS + H_2 = H_2S + Fe \quad \ldots\ldots\ldots\ldots (2)$$

It will be seen from the iron-rich side of the iron–sulphur binary system given by Rosenqvist and Dunicz,[2] that between 988° and 1365° C., γ-solid solution is in equilibrium with iron–sulphur liquid, the composition of which is fixed by the liquidus curve of the system. For the solubility experiments with pure iron at 1000°, 1200°, and 1335° C., the composition of the mixture in the sulphide furnace was adjusted so that when its temperature was greater than 988° C. the mixture consisted of γ-iron and liquid. This enabled the hydrogen-sulphide/hydrogen ratios to be calculated for experiments carried out above the eutectic temperature.

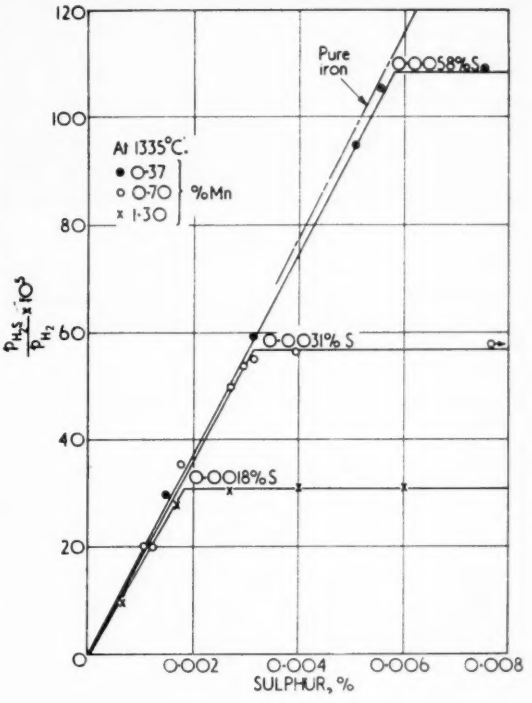

Fig. 5—Solubility of sulphur in 0·37%, 0·70%, and 1·30% Mn–Fe alloys at 1335° C.

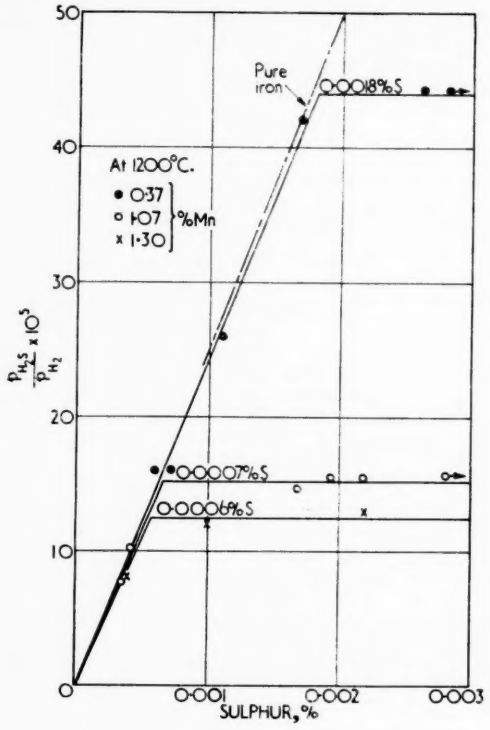

Fig. 4—Solubility of sulphur in 0·37%, 1·07%, and 1·30% Mn–Fe alloys at 1200° C.

The hydrogen-sulphide/hydrogen ratios along the liquidus curve have been calculated from the relationship in Fig. 2, which is obtained from the results of Rosenqvist and Dunicz[2] and Rosenqvist.[4]

Solid Solubility of Sulphur in γ-Iron

The solid solubility of sulphur in γ-iron was determined at three temperatures, i.e. 1000°, 1200°, and 1335° C. In Fig. 3 the hydrogen-sulphide/hydrogen ratio is plotted against the weight-percentage of sulphur dissolved in iron. The horizontal portion of the diagram gives the gas ratio in equilibrium with γ-iron and an iron–sulphur melt. The sulphur contents corresponding to the intersection points are the solid solubilities at 1000°, 1200°, and 1335° C.

Solid Solubility of Sulphur in Iron–Manganese Alloys

Because manganese sulphide is more stable than ferrous sulphide the presence of manganese in iron should reduce the sulphur solubility, and this reduction in solid solubility should become more prominent as the proportion of dissolved manganese increases.

The experimental results on 0·37%, 1·07%, and 1·30% Mn–Fe alloys at 1200° C., are shown in Fig. 4. The horizontal part of the diagram gives the gas ratio in equilibrium with γ-iron–manganese solid solution and almost pure manganese sulphide. Calculations, based on the available thermodynamic data on

sulphides[4, 5] and on the assumption that iron–manganese and ferrous-sulphide/manganese-sulphide systems form ideal solutions, indicate that at 1200° C. the manganese-sulphide/iron-sulphide solution in equilibrium with a 0·37% Mn–Fe alloy should contain about 94% of manganous sulphide.

Figure 5 gives the experimental results on 0·37%, 0·70%, and 1·30% Mn–Fe alloys at 1335° C. The diagram is similar to Fig. 4 and is self-explanatory.

DISCUSSION

Theoretical Considerations

The reaction taking place in the present experiments may be represented by the following equation:

$$H_2(g) + [S] = H_2S(g) \quad \ldots\ldots(3)$$

where [S] indicates sulphur dissolved in the γ-phase. The equilibrium constant of this reaction may be written as

$$K_1 = \left(\frac{p_{H_2S}}{p_{H_2}}\right)\frac{1}{[S\%]} \quad \ldots\ldots(4)$$

and the slopes of the lines in Fig. 3 give the value of K_1 thus:

Temp.	[S%]	$(p_{H_2S}/p_{H_2}) \times 10^3$	K_1
1000° C.	0·0126	5·45	0·433
1200° C.	0·0310	7·90	0·255
1335° C.	0·0456	8·70	0·191

From these values the following equation may be derived:

$$\log K_1 = + \frac{2157}{T} - 2{\cdot}058 \quad \ldots\ldots(5)$$

In these calculations the weight-percentage of sulphur is used instead of its activity; this is justified at such low sulphur concentrations, particularly as it can be seen from Fig. 3 that the solution of sulphur in γ-iron obeys Henry's law. According to the results obtained by Sherman, Elvander, and Chipman[6] the interaction parameter, i.e.

$$e_S^S = \frac{\partial \log f_S^S}{\partial [S\%]} \quad \ldots\ldots(6)$$

in iron–sulphur binary melts is −0·03 at 1600° C.; at lower temperatures, particularly in the solid state, the value of this factor will decrease. Assuming that the value of e_S^S at 1200° C. has dropped to as low as −0·1, then at a sulphur concentration of 0·025% the sulphur activity will be 0·0248. The difference between these two values is too small to detect by analysis and the sulphur activity coefficient can be taken as unity.

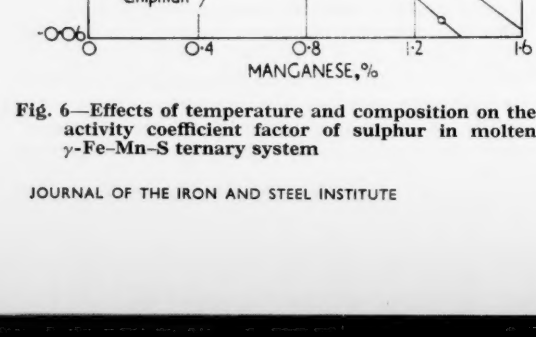

Fig. 6—Effects of temperature and composition on the activity coefficient factor of sulphur in molten γ-Fe–Mn–S ternary system

Equations (4) and (5) hold good also in the presence of manganese, provided that due allowance is made for the effect of manganese on the activity coefficient of dissolved sulphur. The magnitude of this effect is given by the ratio K_1'/K_1, where K_1' is the slope of the lines in Figs. 4 and 5 and K_1 is calculated from equation (5). The following are the values obtained at two temperatures studied:

[Mn%]	[S%]	$(p_{H_2S}/p_{H_2}) \times 10^3$	K_1'	f_S^{Mn}
		At 1200°C.		
0·37	0·0018	0·440	0·244	0·957
1·07	0·00066	0·152	0·230	0·902
1·30	0·00056	0·125	0·223	0·874
		At 1395°C.		
0·37	0·0058	1·085	0·187	0·974
0·70	0·0032	0·570	0·178	0·927
1·30	0·0018	0·310	0·172	0·896

The effect of manganese on the activity coefficient of dissolved sulphur is shown in Fig. 6, where the broken line is that obtained by Sherman and Chipman[7] for iron–manganese–sulphur melts at 1600° C. According to the relationship in Fig. 6, manganese–sulphur interaction in iron increases with falling temperature, as would be expected from thermodynamic considerations. From the lines in Fig. 6 the following equation may be written to represent the variation of $\log f_S^{Mn}$ with temperature and composition:

$$\log f_S^{Mn} = \left(-\frac{215}{T} + 0{\cdot}097\right)[Mn\%] \text{ in } \gamma\text{-iron} \quad \ldots\ldots(7)$$

From equation (7) it follows that the relative partial molal heat of solution of sulphur at any concentration up to the solubility limit in γ-iron–manganese alloys is

$$\Delta \overline{H}_S = -980\,[Mn\%] \text{ cal.} \quad \ldots\ldots(8)$$

when the standard state of sulphur is an infinitely dilute solution in which [Mn] → 0 and in which $f_S^{Mn} \rightarrow 1{\cdot}0$.

According to the work of Smith,[8] manganese lowers the activity coefficient of carbon dissolved in γ-iron. From his experimental results the following equation can be derived:

$$\log f_C^{Mn} = -0{\cdot}019\,[Mn\%] \quad \ldots\ldots(9)$$

in γ-iron at 1000° C. and for the composition range 0·0–0·5% C and 0·0–10·0% Mn.

The factor f_C^{Mn} is defined as

$$f_C^{Mn} = f_C/f_C^C \quad \ldots\ldots(10)$$

where f_C^C and f_C represent the activity coefficients of carbon dissolved in iron–carbon and iron–manganese–carbon alloys, respectively; in infinitely dilute solutions $f_C^C = f_C \rightarrow 1{\cdot}0$.

At 1000° C. and for a given manganese concentration, the value of f_S^{Mn} is about 0·88 times the value of

f_C^{Mn}. This is to be expected from the comparison of the free energies of formation of MnS and 'Mn_3C,' i.e. about −45 and −3 kcal. at 1000° C., respectively.[5, 9] In other words, greater interaction between manganese and sulphur as compared with that between manganese and carbon can account for the value of f_S^{Mn} being less than that of f_C^{Mn} under similar conditions.

The following method may be used to estimate the solid solubility of sulphur in γ-iron–manganese alloys at temperatures and compositions different from those examined in the present work.

The equilibrium constant of the reaction

$$(MnS) = [Mn] + [S] \quad \ldots\ldots(11)$$

is

$$K_2 = [Mn\%][S\%]f_S^{Mn} \quad \ldots\ldots\ldots\ldots\ldots(12)$$

if it is assumed that the manganous sulphide formed is pure enough to have unit activity, i.e. at manganese concentrations greater than about 0·3%, and that the activity coefficient of dissolved manganese is unity. The following values of K_2 are derived from the present work:

$$K_2 = 6{\cdot}38 \times 10^{-4} \text{ at } 1200^\circ \text{ C.}$$
$$K_2 = 20{\cdot}90 \times 10^{-4} \text{ at } 1335^\circ \text{ C.}$$

and therefore the variation of log K_2 with temperature may be written:

$$\log K_2 = -\frac{9020}{T} + 2{\cdot}929 \quad \ldots\ldots\ldots\ldots\ldots(13)$$

The value of K_2 derived from this equation is to all intents the true equilibrium constant of reaction (11). It can be used when the iron–manganese alloys contain less than about 0·3% of manganese only if the activity of manganous sulphide is introduced into equation (12), because at these concentrations the manganous sulphide inclusions will contain appreciable quantities of ferrous sulphide.

Practical Considerations

The iron-rich part of the iron–sulphur phase diagram, based on the results of Rosenqvist and Dunicz[2] and the present work, is shown in Fig. 7. From the solubility diagram it can now be predicted that pure iron–sulphur alloys containing less than 0·01% S should not be subject to hot-shortness during the entire hot-working operation because no liquid sulphide can form. On the other hand, an iron containing 0·02% S will produce a small quantity of a liquid phase as its temperature falls below 1100° C. and the presence of this liquid phase along the grain boundaries will no doubt be a cause of the weakness of the metal.

The improvement in the hot workability of iron–sulphur alloys caused by the presence of manganese may be elucidated by the following example. Consider an Fe–Mn–S alloy containing 0·40% total Mn and 0·02% total S. At 1200° C. almost all the sulphur will combine with manganese, leaving a very small proportion of sulphur (0·0018%) and 0·37% Mn in solution; as already pointed out, the sulphide phase formed will consist of almost entirely pure and therefore solid manganous sulphide. As the alloy is cooled to, for example, 900° C. the sulphur solubility will decrease, but the quantity of the sulphide precipitating will be negligible compared with that which occurs in the pure iron–sulphur binary system.

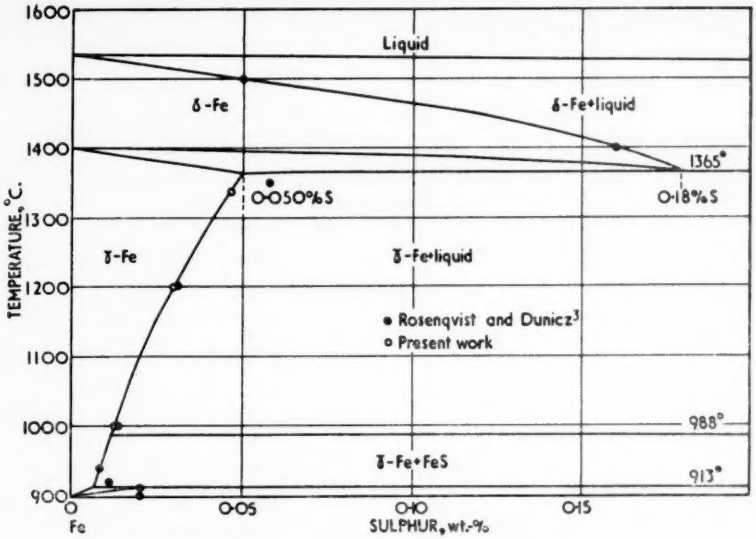

Fig. 7—Iron-rich corner of the Fe–S binary phase diagram

Anderson, Donaldson, Kimball, and Cattoir[10] have recently investigated the forgeability of steels with varying proportions of manganese and sulphur. They found that manganese-free steels with over 0·017% of sulphur could not be forged. They also found an empirical relationship

$$[Mn\%] = 1{\cdot}25\,[S\%] + 0{\cdot}03 \quad \ldots\ldots\ldots\ldots(14)$$

If [Mn%], for a given sulphur content in iron, is greater than that computed from equation (14), the metal is forgeable.

CONCLUSIONS

The solubility of sulphur in γ-iron is 0·013%, 0·031%, and 0·046% at 1000°, 1200°, and 1335° C., respectively. In the presence of 0·37%, 1·07%, and 1·30% of manganese, the sulphur solubility is reduced to 0·0018%, 0·0007%, and 0·0006%, respectively, at 1200° C. In iron–manganese alloys containing 0·37%, 0·70%, and 1·30% of manganese, the solubility of sulphur at 1335° C. is 0·0058%, 0·0031%, and 0·0018%, respectively.

The sulphurization of iron and its alloys by hydrogen-sulphide/hydrogen mixtures may be represented by the following reaction:

$$H_2(g) + [S] = H_2S\,(g)$$

and its equilibrium constant may be written as:

$$K_1 = \frac{p_{H_2S}}{p_{H_2}} \frac{1}{[S\%]f_S}$$

$$\log K_1 = \frac{2157}{T} - 2{\cdot}058$$

The value of f_S in iron–sulphur binary alloys is shown to be unity. Dissolved manganese lowers the activity coefficient of sulphur and the magnitude of the effect varies with temperature and the manganese content of the alloy; thus

$$\log f_S^{Mn} = \left(-\frac{215}{T} + 0{\cdot}097 \right) [Mn\%] \text{ in } \gamma\text{-iron}$$

Dissociation of manganous sulphide to manganese and sulphur in solid solution may be represented by the following reaction:

$$(MnS) = [Mn] + [S]$$

the equilibrium constant of which is

$$K_2 = \frac{[Mn\%][S\%]f_S^{Mn}}{(a_{MnS})}$$

$$\log K_2 = -\frac{9020}{T} + 2{\cdot}929$$

If manganese in solution is more than about 0·3% the activity of manganous sulphide can be taken as unity.

From the present experimental results it is clear that in the absence of manganese hot-shortness may occur in iron containing more than 0·01% of sulphur. In the presence of manganese, sulphur solubility is appreciably reduced, the amount of sulphide inclusions formed on cooling from the range 1200–1300° C. is almost negligible, and the manganous sulphide inclusions, which may also contain some ferrous sulphide, are solid over wide ranges of temperature and composition.

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The Errors Introduced into Diamond Pyramid Hardness Testing by Tilting the Specimen

By T. O. Mulhearn, B.Sc., and L. E. Samuels, B.Met.E.

SYNOPSIS

The errors are found to result from relative lateral movement between specimen and indenter. They depend solely on the angle of tilt and should not exceed 1% if the tilt angle is less than 2°. The practical consequence is that any impression showing the slightest signs of asymmetry should be rejected. A more critical method of checking the symmetry of the impression has been devised.

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IT IS WELL KNOWN that one of the major possible sources of error in diamond pyramid hardness testing is lack of normality between the indenter axis and specimen surface. British Standard Specification 427 : 1931 (Diamond Pyramid Hardness Numbers) requires that the surface tested shall be "supported rigidly at right-angles to the axis" of the indenter, and Hindley* lists this factor as one of the sources of variation in hardness number. No quantitative information is available, however, as to the magnitude of the errors introduced. The purpose of the present investigation was to obtain this information and to determine the acceptable limits for sound hardness-testing practice.

List of Symbols

D = True diagonal of normal impression
D_V = Vertical diagonal of tilt impression
D_H = Horizontal diagonal of tilt impression
D_M = Mean diagonal of tilt impression = $\frac{1}{2}(D_H + D_V)$
d_V = Increase in vertical diagonal = $D_V - D$
d_H = Increase in horizontal diagonal = $D_H - D$
d_M = Increase in mean diagonal of tilt impression = $D_M - D$.

EXPERIMENTAL METHODS

The testing procedure adopted was to carry out comparative hardness tests on specimens of uniform hardness with the specimen surface truly normal to the indenter axis and inclined at known angles to this

* W. N. Hindley, *J. Iron Steel Inst.*, 1945, No. 2, pp. 245P–254P.

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position. The tests were carried out under conditions representative of almost the full range likely to be encountered in practice by varying the indenting load and the hardness and material of the test specimen.

The tests were carried out on a commercial Vickers hardness-testing machine, the measuring microscope of which was calibrated against a stage micrometer and the indenting load by means of a lever balance arrangement. The one indenter was used throughout, and was selected as being of particularly high quality; the included angle of the face was 136° 25′ and the edge projections were square within 2′. The length of the chisel point at the pyramid apex was less than 0·001 mm.

Details of the materials on which the tests were made are set out in Table I. In all cases, the specimens were specially selected for uniformity of hardness. The specimens were mounted in Bakelite and given a full metallographic polish by the method described by one of the authors.* When re-preparation of a surface was necessary, ample material was removed on abrasive papers to eliminate completely the effects of the previous hardness impressions. The working face and opposite face of the mount were prepared so as to be flat and parallel.

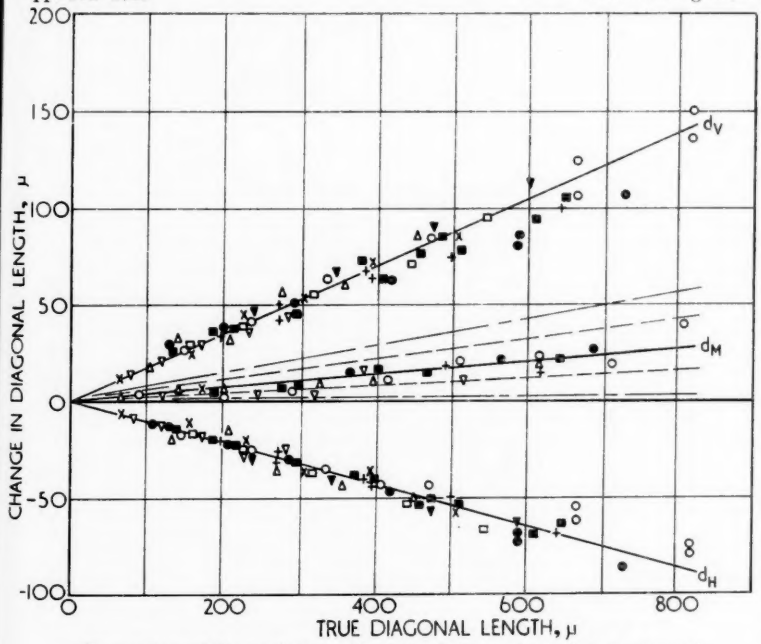
In order to obtain a predetermined and reproducible angle between the indenter axis and the normal to the specimen surface, the specimen mounts were set on tapered blocks which were prepared to angles nominally of 2°, 4°, 6°, and 8° (actual angles: 1° 58′, 3° 56′, 5° 56′, and 7° 57′). This angle will be referred to as the 'tilt angle' (ϕ). The tilt angle was also set at a known orientation with respect to the diagonals of the indenter, and this angle will be referred to as the 'rotation angle' (θ). This was adjusted by setting the edge of the tapered blocks along lines scribed on the table of the hardness machine to correspond with rotation angles of approximately 0°, 15°, 30°, and 45°.

The experimental procedure was to make an impression at the required tilt and rotation angle, return the specimen to the flat position, and make a normal impression adjacent to each tilt impression under the same indenting load. In this way, a direct comparison could be made of the changes in the diagonal lengths introduced by tilting the specimen. All measurements of diagonal lengths were made with the specimen in the flat position, as the whole impression could then always be sharply focused during measurement. Preliminary tests showed that the difference between measurements made at the flat and tilt positions never exceeded 0·5%, which is less than other unavoidable variations in readings.

Table I

MATERIALS INVESTIGATED

Material	Nominal Hardness, D.P.N.	Symbol used in Fig. 1
Brass, cold-rolled (B.S. STA7: CZ5)	83	○
Aluminium alloy (B.S. STA7: AW4)	105	●
Austenitic 18/8 Cr–Ni steel	160	▼
Aluminium alloy, heat-treated (B.S. STA7: AW16)	185	□
Low-carbon steel, normalized (B.S. 970: En5)	210	■
Medium-carbon steel, normalized (B.S. 970: En9)	250	–
Magnet steel (1% C, 1% Cr) heat-treated to various hardness values	360	×
	445	△
	715	▽



Regression of the variation of length of the vertical (d_V), horizontal (d_H), and mean (d_M) diagonals, with confidence levels for d_M for single reading and mean of five readings.

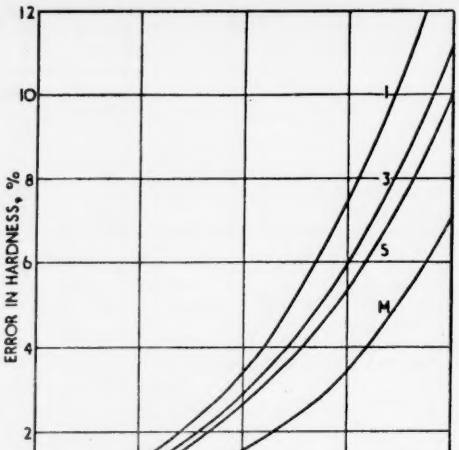
The experimental points for d_V and d_H are for 0° rotation, and from these the regression and confidence lines were calculated. The experimental points plotted in the d_M band are for other rotation angles. The key to the plotted points is given in Table I.

Fig. 1—Variation in length of diagonals with change in length of true diagonal at 8° tilt

RESULTS OF HARDNESS TESTS

The results of tests carried out at a tilt angle of 8° and 0° rotation on the specimens listed in Table I are summarized graphically in Fig. 1. The points are plotted as the increase or decrease in the length of the diagonals of the tilt impressions with respect to impressions made on the flat, i.e. to the true diagonal length under the particular conditions of test.

* L. E. Samuels, *J. Inst. Metals*, 1952–1953, vol. 81, pp. 471–478.



M = mean error in hardness number
5, 3, 1 = likely maximum error for mean of five readings, three readings, and a single reading, respectively

Fig. 2—Variation of error in hardness number with angle of tilt

The length of the diagonal in the direction of slope, which will be termed the 'vertical' diagonal, was always appreciably greater than the true diagonal length, whereas that of the diagonal in the direction at right-angles (the 'horizontal' diagonal) was always less than the true length. In spite of the precautions taken, the experimental points showed an appreciable scatter, but appeared to be distributed about a straight line passing through the origin. The extent of scatter also appeared to increase with impression size. It was apparent, moreover, that the only important variable was the size of the impression; hardness, indenting load, and type of material appeared to be of no significance except in so far as they affected the size of the impression.

This data has been statistically treated by a method due to Douglas which is described in Appendix I, the lines drawn in Fig. 1 being the regressions of d_V, d_H, and d_M on D as calculated by his method; in the last case, the 95% prediction intervals both for a single further reading or for the mean of five further readings are also indicated. Since d_H and d_V are in opposition, d_M is considerably less than either d_H or d_V.

The above discussion is concerned entirely with a 0° rotation angle. Other rotations are best compared on the basis of the variation of d_M with D. This was investigated on the same specimens for rotation angles of 15°, 30°, and 45°, and the values determined are also plotted in Fig. 1. All the points lay reasonably within the prediction intervals calculated for 0° rotation; furthermore, application of the Student-t test showed no evidence that a significant difference existed.

The regression coefficient (c) of d_M therefore represents a proportional error in the true diagonal which is characteristic of the angle of tilt, and which is independent of all other conditions of test. The percentage error in hardness number (ΔH_D) is related to the regression coefficient by

$$\Delta H_D = 2\frac{d_M}{D} \times 100$$
$$= 200c$$

provided that d_M is small compared with D, which is so in the case under consideration.

This value of ΔH_D is the estimated error in hardness number when the results of a large number of impressions are averaged. It is also desirable to have some estimate of how great the error is likely to be with a single impression, or with the average of a small number of impressions. The 95% prediction interval for ΔH_D can be calculated for a single additional reading, or for the mean of three or five further readings, from the experimental determinations at the four tilt angles; smooth curves have been drawn through these calculated values in Fig. 2. These curves indicate the maximum error which is likely to be encountered in practice under the particular conditions of test. The results of a very large number of impressions would have to be averaged in order to attain the theoretical mean error (M of Fig. 2.) Statistical considerations indicate, however, that a substantial reduction in the maximum likely error results when only a relatively small number of readings is averaged; in the present case, the most gainful number appears to be about 3–5, and this was the reason for the choice of these numbers in the construction of Fig. 2.

When considered in conjunction with normal measuring errors, it is apparent that serious errors (exceeding 1%) in hardness number are not likely if the angle of tilt is less than 2°. Thereafter, the error increases rapidly, particularly if the tilt angle exceeds 4°. It would appear undesirable, therefore, to exceed a tilt angle of 2° in practice.

SOURCE OF ERROR

Simple calculations show that the magnitude of the error found is considerably greater than that to be expected from simple geometrical considerations, i.e. the error which results from the use of the mean diagonal in the standard formula for calculating the pyramidal area of the impression instead of calculating the area from the known two diagonal values.

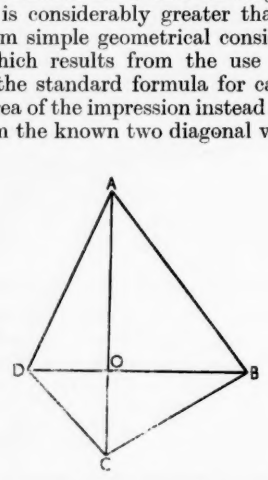


Fig. 3—Sketch of typical tilt impression

Observations made during the tests tended to suggest that the abnormally large impressions resulted from relative movement between the specimen and indenter caused by the unsymmetrical loading. The existence of the relative movement was confirmed in the following way. A fine line was scribed across a specimen, which was then set in the 8° tilt block at 0° rotation. The specimen was positioned so that the horizontal diagonal of the indenter was exactly coincident with the back edge of the scribed line. This was checked by making a small impression with a 1-kg. indenting load. The main impression was then made with a 50-kg. indenting load. The horizontal diagonal of the resultant impression was quite noticeably displaced 'downhill' from the reference line (*see* Fig. 6.) Moreover, the extent of the lateral movement fully accounted, within the accuracy of measurement, for the error in hardness number. The impression of Fig. 6 also illustrates well the 'piling-up' of the specimen surface on the downhill side of the impression, which is characteristic of impressions made on tilted surfaces (*see* Fig. 7); the piling-up apparently results from the ploughing action of the indenter as it moves downhill.

On this basis, it might be expected that the error could be eliminated if lateral movement of both the specimen and the indenter could be completely prevented. It is very doubtful, however, whether this condition could be achieved in practice. The specimen may be rigidly clamped to the table of the hardness-testing machine, but there must inevitably be some slackness in the indenter guide mechanism which will permit some lateral movement of the indenter point. Only very small amounts of lateral movement are necessary for the development of the error; even in the extreme case illustrated in Fig. 6 the movement was only 35μ.

GEOMETRY OF TILT IMPRESSIONS

The appearance of impressions made at representative tilt and rotation angles is shown in Fig. 7. The asymmetry is so slight at a tilt angle of 2° that it would not easily be detected in normal hardness-testing practice except, perhaps, when the rotation

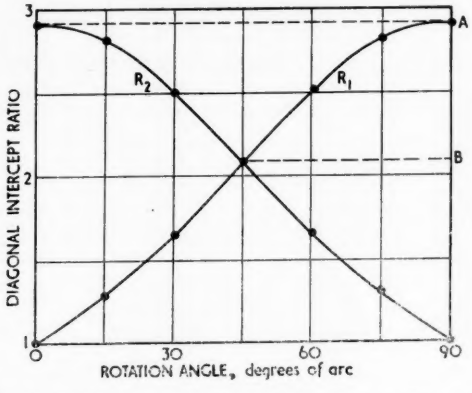
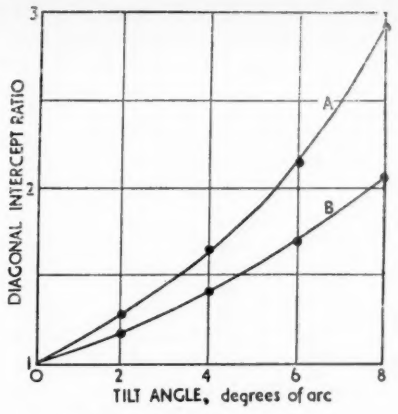


Fig. 4—Variation of diagonal intercept ratios with rotation angle for 8° tilt



A and *B* are the values indicated in Fig. 4

Fig. 5—Variation of the range of the larger diagonal intercept ratio with angle of tilt

angle approaches 45°. As discussed above, a tilt angle of 2° is probably the maximum acceptable in practice. It would seem desirable, therefore, to develop some quantitive method for determining whether the specimen tilt has been within reasonable limits.

There are three ratios of impression dimensions (Fig. 3) which are related to the angle of tilt, namely:

(i) The ratio of the diagonal lengths, i.e. AC/DB. This ratio is not a suitable measure of tilt angle since it approaches unity as the rotation angle approaches 45°, irrespective of the tilt angle

(ii) The ratio of the dimensions of opposite sides of the impression, i.e. AB/CD or AD/CB in Fig. 3. This ratio is not as conveniently determined as the ratio discussed under (iii)

(iii) The ratio of segments into which one diagonal is cut by the other diagonal, i.e. AO/OC or BO/OD in Fig. 3. These ratios can be determined by making only two additional measurements, those of AO and OD. All further attention was therefore confined to these ratios, which will be termed the 'diagonal intercept ratios' (R). The ratios will be standardized here as the ratio of the longer intercept to the shorter, and are therefore always greater than unity.

If it is assumed that the shape of the impression is geometrically similar to that of the indenter, the two values of the diagonal intercept ratio at any tilt and rotation angle can be calculated (*see* Appendix II.) As an example, the values of R so calculated for the particular value of $\phi = 8°$ have been plotted against the rotation angle in Fig. 4. If the larger of the values of R for the two diagonals is chosen, the ratio will always fall between the two values A and B in Fig. 4, the ratios at 0° and 45° rotation, respectively. This range of values is characteristic of the particular tilt angle. The characteristic ranges have been calculated for a series of tilt angles and these results were used to draw the curves in Fig. 5. The points plotted in Fig. 5 are experimentally determined values, and the agreement with the calculated curves is very good, indicating that the original assumption about the geometry of the impression is justified, at least for the present purposes.

The most that can be deduced from these intercept ratios is that the tilt angle has been within a certain range; if, however, both ratios are less than the lower limit of the range shown in Fig. 5 for a certain angle, the tilt has been less than that particular angle: e.g. if both ratios are less than 1·3, the tilt angle must have been less than 2°.

SUMMARY

The results of the investigation indicate that the error in hardness number resulting from tilting of the impression is not likely to exceed 1% if the angle of tilt is less than 2°, particularly if the results of several impressions are averaged. The likely error increases rapidly with increasing angles of tilt, and substantial errors are likely if the angle exceeds 4°. It is suggested that, as a reasonable working rule, a tilt angle of 2° is the maximum permissible in sound hardness-testing practice.

The most reliable method of assessing whether the tilt has been within these limits is from the appearance of the impression itself. A study of Fig. 7 will indicate that the asymmetry is scarcely detectable at 2° tilt unless the rotation angle has been close to 45°. If, therefore, the assessment is made solely on the visual appearance of the impressions, the standards must be made quite rigorous, i.e. impressions showing any signs of asymmetry must be rejected. Comparison with a chart such as that shown in Fig. 7 greatly assists the visual assessment of impressions. Measurement of the diagonal intercept ratios of an impression provides a more quantitative method of control, and could be used for assessing an impression for which the acceptability is in doubt. If both these ratios are less than 1·3, the tilt angle has certainly been less than 2°, and it is then known that no appreciable error has been introduced by tilting of the specimen.

The results of the investigation also suggest that it would be extremely difficult in practice to maintain a higher standard than that proposed above. It follows, therefore, that errors in hardness number of 0·5–1% due to this factor are always possible. The investigation confirms the desirability of averaging the results of several impressions in practical hardness testing. So far as the error under discussion is concerned, it would appear desirable to average 3–5 determinations.

Acknowledgments

The assistance received from the National Standards Laboratory, C.S.I.R.O., who calibrated the hardness-testing machine and carried out the measurements on the indenter used in this investigation, and from Mr. J. B. Douglas in the statistical treatment of the data, is gratefully acknowledged. The paper is published by permission of the Chief Scientist, Department of Supply, Australia.

APPENDIX I

Method of Statistical Treatment of Data

By J. B. Douglas, B.Sc., M.A.

Suppose D is a (controlled) variable with the random variable d related to it by

$$d = \gamma D + U_D$$

where γ is an unknown constant and U_D is a normally distributed variate with zero mean and standard deviation $D\sigma$, σ being an unknown constant. Then, given a set of observations

$$(D_1, d_1), (D_2, d_2) \ldots (D_i, d_i) \ldots (D_n, d_n),$$

which, with $Z_i = d_i/D_i$, may be written as

$$Z_1, Z_2 \ldots Z_i \ldots Z_n,$$

appropriate estimators of γ and σ^2 are, respectively,

$$\frac{1}{n}\sum_{i=1}^{n} Z_i = c, \text{ say,}$$

$$\frac{1}{n-1}\left\{\sum_{i=1}^{n} Z_i^2 - nc^2\right\} = S^2, \text{ say.}$$

These two estimators are independently distributed, the distribution of c being normal with mean γ and variance σ^2/n, whilst $(n-1)S^2/\sigma^2$ is distributed as χ^2 with $n-1$ degrees of freedom. Confidence intervals for γ and σ^2 may thus be obtained.

Supposing the linear regression has been estimated as above from n observations, by the relation $d = cD$, it may then be required to predict for some given $D = D_0$ a range of values within which, with a specified probability, the mean of a further m observations would be expected to lie. The predicted value is cD_0, and the prediction interval with confidence coefficient α for the mean is

$$cD_0 \pm t_\alpha D_0 S\sqrt{\left(\frac{1}{m} + \frac{1}{n}\right)},$$

where t_α is the two-tailed Student-t value corresponding to

$$\Pr(|t| < t_\alpha) = 1 - \alpha$$

for $n-1$ degrees of freedom.

It may be noted that the assumptions of the mathematical model imply that

(i) The underlying relation is linear with a zero constant term

(ii) The observational errors are normally distributed about the linear expression with a standard error proportional to the value of the controlled variable.

APPENDIX II

Calculation of Diagonal Intercept Ratio

The ratio (R) is related to tilt and rotation angles as follows:

$$R = \frac{\cot\alpha + \tan\beta}{\cot\alpha - \tan\beta}$$

where α is the half angle included between the indenter corners (74° 3′) and β is as defined below. One value (R_1) is obtained when

$$\tan\beta_1 = \tan\phi \sin\theta$$

and the second value (R_2) when

$$\tan\beta_2 = \tan\phi \cos\theta.$$

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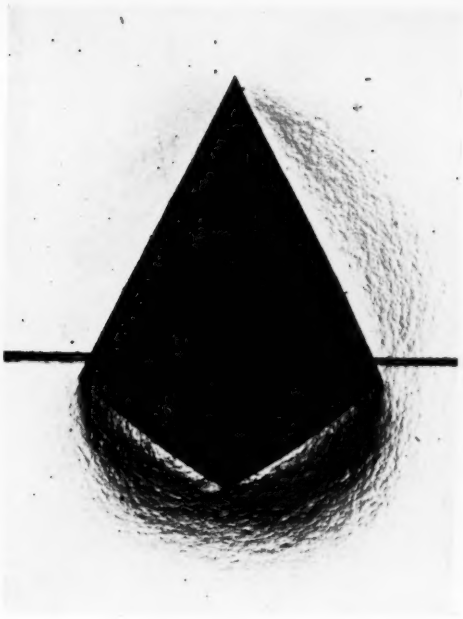

Fig. 6—Impression (8° tilt, 0° rotation), illustrating relative movement between indenter and specimen. Scribed line was aligned coincident with indenter diagonal before indentation × 100

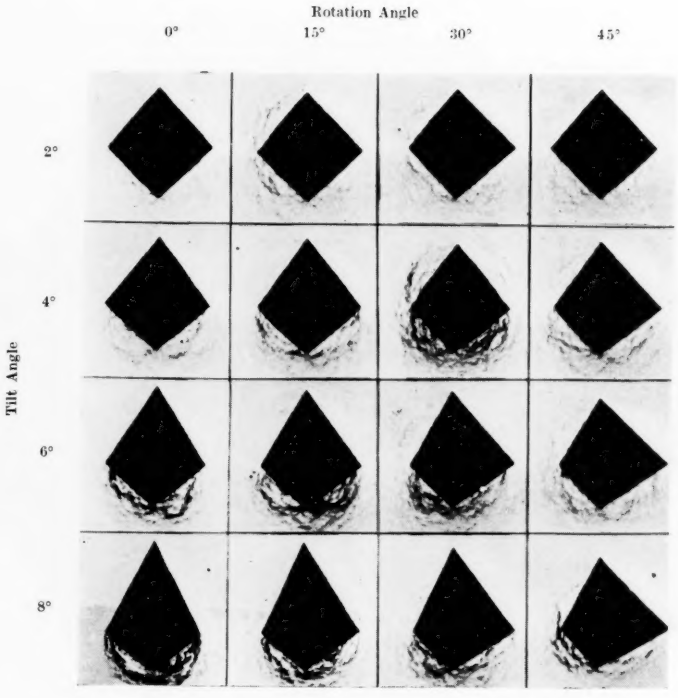

Fig. 7—Representative tilt impressions × 75

The Enthalpy and Specific Heat of Iron and Steel

A CRITICAL SURVEY OF THE METHODS OF DETERMINATION

By J. R. Pattison, B.Sc., D.I.C., Ph.D., A.Inst.P.

SYNOPSIS

A short description is given of the various methods for the measurement of the enthalpy and specific heat of iron and steel and the available experimental data for pure iron are compared and criticized. A table of the true specific heats up to 1000° C. and the heat contents up to 1400° C. is compiled from the selected data. Above 1400° C. where insufficient data are available for a reliable estimation of total heat content, it is suggested that the position could be clarified by further experimental work. In the meantime it is proposed that the most reliable figure for the latent heat of melting of iron is 64·4 cal./g. as obtained by Oberhoffer and Grosse, which is supported by calculations from the depression of the freezing point.

The direct determination of the total heats for steels up to the melting range has only been carried out for one steel, so that a considerable amount of work is necessary in this field. 1167

THE ENTHALPY AND SPECIFIC HEAT of metals have been subject to a considerable amount of research during the last hundred years. A number of these researches have included iron and steel but only four investigators have extended their temperature range beyond the melting point of iron, and only one set of measurements of the enthalpy of any steel above the melting range has yet been published.

A knowledge of the heat content of steel is necessary in order to assess the fuel consumed in soaking ingots before rolling and also to provide data for estimating rates of solidification in the continuous casting process. A considerable saving of fuel would become possible if the skin thickness of a solidifying ingot could be accurately calculated from a measurement of the rate of loss of heat from the ingot, for the ingot could then be removed from its mould and into a soaking pit while containing the optimum quantity of heat. Continuous casting of steel into billets in a water-cooled mould depends for its success on the formation of a skin strong enough to withstand the tension applied to overcome friction between billet surface and mould.

METHODS OF MEASUREMENT

The methods of measurement of the total and specific heats of a metal in the solid or liquid state may be separated into two classes, namely:

(i) The direct measurement of specific heats from the amounts of heat involved in making a small temperature change at the temperature at which the specific heat is required. The total heats over a range of temperatures may be obtained indirectly by integration of the specific-heat/temperature curve

(ii) The direct measurement of the total heat contained by a specimen at a given temperature by the method of mixtures. The specific heat at the given temperature may be indirectly computed by differentiation of the total-heat/temperature curve.

There is another method of rather limited application:

(iii) The derivation of the latent heat of fusion from known data for the depression of the freezing point by the addition of solutes.

The Measurement of Specific Heats

The first method in this classification was originally suggested by Corbino[1–3] and Pirani[4] and employs a lamp filament for the specimen. The heating current in the filament is changed by a small amount and the change in temperature is equated with the change in power input determined by measurements of filament current and resistance. The temperature was measured by Corbino with an optical pyrometer, but Pirani used a thermocouple in order to investigate the 100–1000° C. range. Worthing[5] eliminated end cooling effects and Gaehr[6] used cyclic changes of filament current to obtain steady state conditions. Hunkel[7] used the electron emission from tungsten filaments to evaluate their temperatures from Richardson's thermionic current equation. Further improvements in technique were made by Smith and Bigler[8] and Smith and Bockstahler.[9] Bockstahler[10] measured the filament temperatures with an optical pyrometer, using steady currents and relating these temperatures to those existing during current changes by comparing the thermionic emission values.

The filament method does not appear to give results of high accuracy. Worthing[5] found considerable differences between the values obtained while progressively increasing the temperature and those obtained while decreasing the temperature, and he was unable to account for these differences. In spite of the improved technique of subsequent investigators, their results show considerable scatter, possibly because the small mass of the specimen makes it sensitive to small changes of input energy.

An early attempt to measure specific heats in a constant temperature enclosure was made by Lecher[11] using a length of wire placed in a furnace. A known amount of energy was added by passing an alternating current through the wire and the ensuing temperature changes were measured by four thermocouples placed along it. Again, the specimen was small and sensitive to small changes of input energy, and the first accurate measurements with this method were made by Griffiths and Griffiths[12, 13] using relatively large specimens enclosed in an oil bath. By supplying a measured quantity of energy to an electrical heater inside the

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specimen its temperature was raised from slightly below that of the enclosure to the same difference above. A platinum resistance thermometer was used and measurements were taken at temperatures up to 100° C. Dearden[14] extended the measurements to 400° C. with a similar apparatus, but instead of using Rumford's method of compensation for the loss of heat to the enclosure he used a cooling curve to correct the measured temperature changes. The direct measurement of specific heats up to 1000° C. was carried out by Klinkhardt[15] in a novel way which makes a heater wire unnecessary by using the specimen as an anode and raising its temperature through small ranges by cathode ray bombardment. The specimen was enclosed in a vacuum enclosure heated externally to any desired temperature before a known quantity of energy was added by bombardment.

The most serious remaining source of error in Griffiths's method is the existence of temperature gradients across the specimens. The influence of these gradients is reduced to a minimum in a modification suggested by Sykes[16] to enable continuous measurements to be taken, and employed by Sykes and Jones[17] and Awbery and Snow.[18] The specimen, containing a small heating coil, is placed in a uniform temperature enclosure inside a furnace and, by means of thermocouples attached to both the specimen and the enclosure, the operator adjusts the furnace current to bring the enclosure to the same temperature as the specimen. This procedure is carried out continuously over a large temperature range with the heating coil passing a continuous current. In this way the effects of emissivity changes are obviated and the specific heats may be calculated directly from the measured input of energy and the subsequent temperature change recorded over small intervals of time. The method has been employed up to 950° C. but a variation of the technique has been used by Pallister[19] to extend the temperature range up to 1300° C.

In Pallister's method, the specimen, in the form of a long **U**-shaped bar, is enclosed in a furnace at a given temperature. A short length of the specimen is defined by the positions of two thermocouples which also serve as potential leads for resistance measurements, the principal thermocouple being welded halfway between them. An electric current pulse of known magnitude is passed through the specimen for a measured short period of time and the increment in temperature measured. From a measurement of the resistance of the particular portion of the specimen involved, the energy dissipated in it may be calculated. The loss of heat by the specimen due to radiation during the period of heating is estimated by the extrapolation of a cooling curve plotted after the cessation of the current. Subsequently, Pallister[20] reduced the radiation losses by employing a rod specimen connected inside, and in series with, a tube of the same material, so that the passage of an electric current heated both the rod and its tube container at the same time. A measuring technique previously used by Baerlecken[21, 22] had some similarity to Pallister's method but used a coil of wire. A plot of the temperature of the coil was taken over a period of time, including the time of passage of the current, and the radiant heat losses were estimated by an extrapolation of the portions of the temperature/time plot preceding and succeeding the time of current flow.

The variations in the shape of the specimen employed by Pallister[19, 20] and Baerlecken[21, 22] do not lend themselves to investigations in the liquid state, but otherwise Sykes's method may be used with the specimen enclosed in a refractory container. Unless the thermal conductivity of the refractory material is independent of temperature, a change in the temperature gradients across the walls of the container, as the temperature of the contents is increased, will cause errors. These errors are eliminated in Smith's method[23] by calibrating with a specimen of known specific heat.

In the arrangement described by Smith[23] the specimen is placed in a refractory container of low thermal conductivity, inside a furnace whose temperature is maintained at a constant difference above or below that of the specimen. If it is assumed that the thermal conductivity of the refractory is independent of temperature, then a constant temperature gradient is maintained across the container walls. Hence the heat gained or lost by the specimen in a given time will be constant and the time taken for the specimen to pass through a given temperature interval will be proportional to the heat absorbed or evolved.

A technique originally proposed by Dulong and Petit[24] has also been used by Jones and Sykes[17] for the measurement of specific heats by a cooling curve. In this arrangement, two specimens of identical surface area and emissivity are placed in a uniform temperature enclosure and cooling curves are taken for both the specimens and the enclosure, starting at identical temperatures. Provided the specific heat of one specimen is known, that of the other may be calculated.

The necessity to employ specimens of known specific heat for the purpose of calibration or comparison involves a reduction in the accuracy of the results and in any case is difficult to fulfil when the temperature range of investigation is being extended. Thus, the cooling curve method of Jones and Sykes[17] and the Smith[23] method are unsuitable for accurate determinations of specific heat at high temperatures.

All these methods for the determination of specific heats require a considerable period of time for their successful completion. Nor is it possible to obtain quick results by reducing the level of accuracy in the determinations. However, Aitchison[25] has described a method in which a curve showing the variation of specific heat with temperature may be obtained quickly and easily, although the accuracy of the determination is lower than that possible by the more involved techniques. The specimen is heated in a high-frequency induction furnace in which it is possible to supply heat to the specimen at a constant rate not dependent on the temperature. A graph is plotted of the rate of rise of temperature against temperature and, with the furnace switched off, a graph of the rate of cooling *v.* temperature is also obtained. The actual rate of absorption of heat by the specimen may thus be determined over the temperature range used.

The Method of Mixtures

The technique of measurement of the enthalpy of solids and liquids by the method of mixtures, using a calorimeter containing water, has not changed

markedly since the experiments of Régnault.[26] The more recent investigations by Umino[27] have differed in detail and in the different heating arrangements necessary at higher temperatures, but the general principles are the same. Umino adopted the methods of Tadokoro,[28] using a copper calorimeter insulated from its surroundings by a layer of asbestos wool. The furnace, containing the specimen in an alumina vessel, was moved to a position over the calorimeter for only the short period of time necessary for the transference of the specimen to the calorimeter. The temperature increase of the calorimeter was measured with a Beckmann thermometer to 0·001° C. and the heat losses were accounted for by the extrapolation of a cooling rate plot. The method is inaccurate if any loss of heat occurs by the formation of steam after the introduction of the specimen into the calorimeter. In order to estimate the heat lost by radiation from the specimen in transit between the furnace and the calorimeter, a separate experiment is carried out with an empty alumina container. This also avoids the necessity of making any assumptions about the thermal properties of the container.

Meliss[29] carried out experiments using a water calorimeter but with additional precautions to avoid the effects of cooling in transition and the formation of steam. The specimen was enclosed in a quartz capsule and suspended inside a nickel tube in the furnace. When a calorimetric experiment was made the following sequence of events was initiated by a mechanical arrangement: the nickel tube was allowed to fall to the lower end of a furnace where it was suddenly arrested so that the specimen suspension was broken; the specimen then fell out of the tube into a double-walled intermediate calorimeter, with an automatically closing lid; and finally, the intermediate container was allowed to fall into the water calorimeter. Since the measured temperature was that of the sleeve, and the radiation from the double-walled intermediate container was small, the error in the measurement of the true temperature of the specimen on entry into the calorimeter should be small. Further, the lower rate at which a state of temperature equilibrium was reached in the calorimeter due to the double wall reduced the possibility of steam formation. These precautions are impracticable above 1500° C.

Any possibility of the evaporation of the calorimetric fluid may be avoided by the use of an ice calorimeter. Here again, only small changes have been made subsequent to the original design by Bunsen[30, 31] but improvements in the calibration by using electrical methods have been made by Dieterici,[32] Griffiths,[33] and Ginnings and Corruccini.[34]

A further method, which does not require a calorimetric fluid, is that employing a metal block calorimeter as proposed by Nernst, Koref, and Lindemann.[35] In this arrangement the temperature rise in the metal block, acting as a calorimeter, is measured by a number of symmetrically distributed thermocouples. The method has been used by Magnus[36–38] and improved models have been described by Grosse and Dinkler[39] and Jaeger and Rosenbohm.[40] Since the actual measured temperatures depend on the heat conductivity of the metal block and the location of the couples, the calibration of the calorimeter involves a more complicated procedure than that of a calorimeter containing a liquid.

The Calculation of Latent Heats

The calculation of latent heats of melting from the van't Hoff equation is often complicated by the lack of data on activity coefficients. This usually leads to the assumption that ideal solutions exist, and this may be valid for solutions of similar substances. However, the polymorphism and good solvent properties of iron make the assumption of ideal solutions particularly unsound for this metal.

COMPARISON OF RESULTS

It is possible to criticize the methods of measurement of the specific and total heats of iron or steel from two aspects: that is, either from the relative suitability of a method or from the experimental technique employed by a particular observer who has used the method. Owing to the lack of measurements, it is difficult to compare measured data for a particular steel, but many investigations of the specific heat and enthalpy of pure iron have been made, and a comparative study of these is relevant.

The Specific Heat of Iron

The most reliable values for the specific heat of iron, over the temperature range 0–100° C., are probably those obtained by Griffiths and Griffiths[12, 13] in experiments which were carried out with considerable care. The extension of the Griffiths method up to 400° C. by Dearden[14] may be criticized because, although the heat absorbed in the heater was neglected, the mass of the heater was not sufficiently small compared with the mass of the specimen. Moreover, although Dearden obtained a pronounced cusp at 120° C. in the specific-heat/temperature curve for pure iron, he did not repeat his experiments in order to confirm it. Naeser[41, 42] was the only other investigator to find pronounced discontinuities in the shape of the specific-heat/temperature curve for iron below the Curie point. These occurred at 198° C., 390° C., and 480° C., so they do not confirm Dearden's results and in any case Naeser used a water calorimeter to measure total heats so that his specific heats are mean values and not true values.

No weight can be attached to the results obtained by Pirani[4] or Lecher,[11] having regard to the low accuracy of the methods employed and the impurity of the specimens. The specific heats of high-purity iron specimens have been measured directly by Klinkhardt,[15] Lapp,[43] Sykes and Evans,[44] Baerlecken,[21] Awbery and Griffiths,[45] and Pallister[20] using Griffiths's adiabatic calorimeter method.

The values obtained by these observers are given in Table I at intervals of 100° C. The maximum specific heat occurring during the A_2 transition, which is generally found between 750° and 760° C., is also tabulated. The values of the specific heat recommended by the writer are given for 100–1000° C.

Up to 600° C. there is reasonable agreement between the observers, excluding Klinkhardt and Lapp. The latter was more interested in the A_2 and A_3 transformations and therefore her results for the 0–600° C. range are based on a small number of measurements.

It is suggested that the most reliable results up to 600° C. are those due to Awbery. The value of 0·114 for the specific heat at 100° C. fits the equation obtained by Griffiths and Griffiths for the specific heat over the 0–100° C. range.

Above 600° C. the effects of the A_2 transition, which are spread over a considerable temperature range, cause greater disagreement between the tabulated results. Some of the disagreement may also be due to the diminution in the accuracy of the method consequent at higher temperatures. In the circumstances, a mean of the tabulated figures at each temperature above 600° C. probably gives the most satisfactory picture of the thermal capacity. The value of 0·305 recommended is taken to represent the maximum effect of the A_2 transition which occurs at 750–760° C., which covers the estimates of the varying observers of the point of maximum influence.

The calculation of true specific heats from a total-heat/temperature curve is difficult, unless the curve is plotted in sufficient detail, so that the direct method using an adiabatic calorimeter is capable of greater accuracy of determination than indirect calorimetric methods. The direct method, however, involves the accurate measurement of small temperature differences, of the order of 2–5° C., at the temperature at which the specific heat is required. This may be readily carried out at room temperatures but with increasing temperature it becomes progressively more difficult to attain the same accuracy. In calorimetry the temperature changes are measured at room temperature or the volume changes at 0° C. so that this difficulty does not occur.

In iron, the total-heat/temperature curve is non-linear from room temperature to the A_3 point and this range includes the A_2 or Curie point, which is not a true transformation point and which influences the total heat over a range of temperature. Up to the A_3 point the direct method of measurement of specific heats would appear to be the most accurate. However, having regard to the reduction in the accuracy of the direct method at higher temperatures and also to the fact that there are more grounds for assuming a linear relationship between the total heat and the temperature between the A_3 and A_4 points, it may be more accurate to accept indirect rather than direct measurements of specific heat above 900° C.

The Enthalpy of Iron

The enthalpy of pure iron has been the subject of considerable investigation since the work of Dulong and Petit[46] and Régnault[47] but most of the early results must be rejected because of the low purity of the iron, the faulty temperature scale employed, and inaccurate methods of calorimeter calibration. The low purity of the iron, alone, excludes all the published work carried out before 1886, when Pionchon[48–50] investigated iron containing what was described as a trace of carbon, phosphorus, and silicon. This work was also the first to be extended to temperatures above the A_3 point but the results obtained are unreliable for a number of reasons. The furnace was heated by gas so that to prevent oxidation of the iron specimen it was enclosed in an envelope of platinum, but even this underwent a rapid deterioration. The temperature scale was based on 907° C. for the melting temperature of silver, whereas the 1948 Temperature Scale[51] gives 960·8° C. The calorimeter was calibrated by the Violle[52] method in which comparative measurements are made using platinum and accepting the values for the enthalpy of this metal previously determined by Violle. Since Violle's experiments were also based on a faulty temperature scale and involve other inaccuracies this method of calibration is unsound.

The results of a number of later investigations with improved methods cannot be regarded as reliable for the following reasons. Harker[53] used the Violle method of calibration. Weiss and Beck[54] used a faulty temperature scale and an unsatisfactory method of correction for the comparatively large platinum envelopes which enclosed their specimens. Weiss, Piccard, and Carrard[55–58] improved on the apparatus of Weiss and Beck but some doubt is thrown on the reliability of their results by the difficulties encountered in preserving the gold envelope designed to protect the specimens from oxidation in the furnace.

The remaining published papers on measurements of the enthalpy of pure iron include only four with direct measurements of the latent heat of fusion. The figures obtained, however, show large variation:

Wüst, Meuthen, and Durrer	(1918)	49·35 cal./g.
Oberhoffer and Grosse	(1927)	64·38 cal./g.
Umino	(1926)	69·20 cal./g.
Umino	(1929)	65·65 cal./g.

In order to analyse these results and those obtained by other investigators at lower temperatures, the total-heat/temperature curves have been plotted from the published figures in Figs. 1 and 2. Since the overlapping was considerable, it was necessary to divide

Table I—THE TRUE SPECIFIC HEAT OF PURE IRON

Temperature, ° C.	Klinkhardt[14]	Lapp[43]	Sykes[44]	Baerlecken[21]	Awbery[45]	Pallister[20]	Recommended Values
100	0·115	0·122	0·114	0·114	0·114	0·114	0·114
200	0·128	0·136	0·125	0·126	0·124	0·124	0·124
300	0·140	0·149	0·135	0·134	0·132	0·132	0·132
400	0·151	0·163	0·144	0·146	0·143	0·144	0·143
500	0·163	0·177		0·161	0·160	0·158	0·160
600	0·189	0·194		0·180	0·180	0·180	0·180
700	0·230	0·222		0·227	0·209	0·217	0·221
A_2	0·320	0·280		0·328	0·280	0·318	0·305
800	0·210	0·203		0·219	0·189	0·199	0·204
900	0·186	0·160		...	0·190	0·157	0·173
1000	0·162	0·142		0·177	0·139	0·136	0·151

Fig. 1 into two separate portions 1*a* and 1*b*, containing a roughly equal number of curves.

The data were obtained from the following sources:

Key	Figure	Observer	Date
○	1*a*	Oberhoffer[58] (ice calorimeter)	1907
●	1*a*, 2	Oberhoffer and Grosse,[60] using a metal block calorimeter	1927
□	1*a*, 2	Umino,[61] using a water calorimeter	1926
■	1*a*, 2	Umino,[62] using a water calorimeter	1929
▵	1*b*, 2	Wüst, Meuthen, and Durrer,[63] using an ice calorimeter	1918
——	1*b*	Meliss,[29] using a water calorimeter	1935
+	1*b*	Jaeger, Rosenbohm, and Zuithoff[64] using a metal block calorimeter	1938
▲	1*b*	Baerlecken,[21] using a specimen of wire for spec. heat determinations	1933
▽	1*b*	"Physical Constants of Some Commercial Steels at Elevated Temperatures,"[65] compiled from the results of Awbery and Snow,[18] Awbery and Griffiths,[45] Awbery and Challoner,[66] and Pallister,[19, 20] using cylinder and wire specimens for specific heat determinations	1953

Where the published figures are not referred to zero heat content at 0° C. they have been converted by the addition of the estimated heat content between 0° C. and the reference temperature, obtained by extrapolation.

The determination of the latent heat of melting from a total-heat/temperature curve requires a sufficient number of readings above and below the melting temperature so that the curves to be extrapolated can be adequately defined. An examination of Fig. 2 shows that only two of the plotted curves fulfil this requirement to any degree. The figures obtained by Umino[61] in 1926 provide only three points above the melting temperature and only one between the A_4 transformation at 1400° C. and the melting temperature. The figures obtained later by Umino[62] give sufficient points below the melting temperature but only two above melting. Oberhoffer and Grosse[60] give four points below the melting point and five above, whereas Wüst, Meuthen, and Durrer[63] give seven points below and four above. It must be concluded that these two investigations should lead to the most reliable figures for the latent heat of fusion of iron but unfortunately the disagreement between them is most pronounced.

Since the two extrapolated curves, from which the latent heat of fusion may be determined, are not parallel, the actual value of the latent heat depends to some extent on the chosen value of the melting temperature. Oberhoffer and Grosse, and Wüst, Meuthen, and Durrer, used 1528° C., and in 1929 Umino used 1530° C. In 1926, however, Umino measured the melting temperature and found it to be 1520° C. It would be preferable to use a measured value of the melting temperature since this prevents the absolute error in the measurement of temperature from affecting the choice of the correct melting point. However, 1520° C. is lower than any other published measurement of the melting temperature of pure iron, which would indicate either a contamination of the thermocouples used by Umino or a low standard in the purity of the iron.

Before attempting any further analysis of the plotted curves in Figs. 1*a*, 1*b*, and 2, it is useful to examine the experimental technique of the respective investigators. Umino used a copper calorimeter with

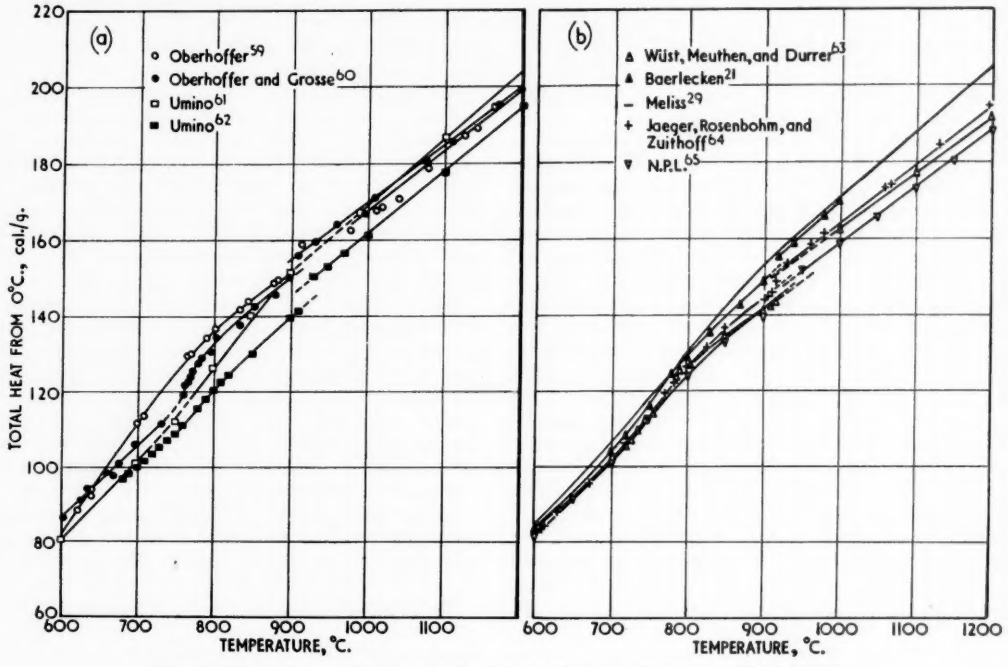

Fig. 1—Total heat of iron obtained by different observers: 600–1200° C.

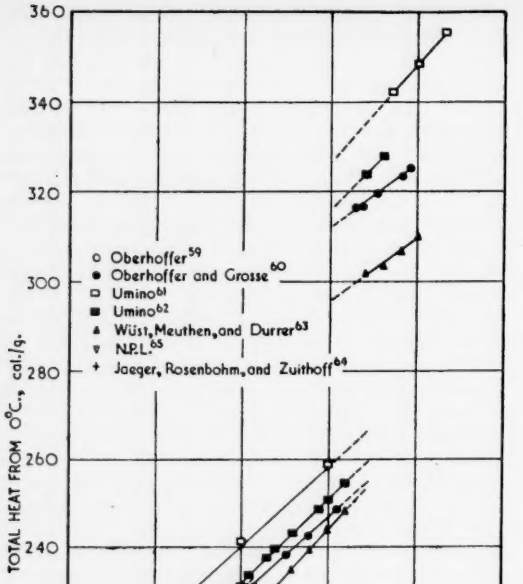

Fig. 2—Total heat of iron obtained by different observers: 1200–1630° C.

a layer of asbestos wool to insulate it from its surroundings. This lagging is bad practice since, owing to the large time constant of the heat transfer process, the rate of loss of heat from the calorimeter depends on its past thermal history. The ice calorimeter was employed by Oberhoffer and later by Wüst, Meuthen, and Durrer to avoid evaporation of the calorimetric liquid. But although these observers took every precaution to avoid errors due to the heat leaking into the calorimeter from the immediate surroundings they neglected the direct radiation from the furnace. The calorimeter and furnace were joined together so that both could be evacuated and the only separation of one from the other was provided by a glass tap which could not provide a very efficient radiation shield. Oberhoffer and Grosse, and Jaeger, Rosenbohm, and Zuithoff using metal block calorimeters, also sited the furnace permanently above the calorimeter but unlike Oberhoffer and Wüst they took sufficient precautions to prevent the calorimeter being irradiated by the furnace. The metal block calorimeter does not require a calorimetric liquid but has the disadvantage that it cannot be calibrated by introducing a known amount of electrical energy through a built-in heater. In fact, Jaeger[40] calibrated a calorimeter by introducing a platinum crucible containing hot water. This destroys the advantage of the metal block over the water calorimeter from the aspect of possible water evaporation.

The enthalpy data obtained by the various observers shows a variation of 2% at 100° C. increasing to 4% at 500° C. Above 500° C. the increased divergence of the different sets of figures is shown in Figs. 1 and 2.

In attempting to draw conclusions from a comparison of the curves plotted in Figs. 1*a* and *b* it is difficult to assess which set of results may be taken as the most reliable. Presumably, more weight may be given to Umino's results for 1929 than his previous results obtained in 1926. Again, Oberhoffer and Grosse's results, obtained in 1927, must be taken as superseding those obtained by Oberhoffer alone in 1907, even though different experimental methods were employed. The improved experimental procedure may be seen in Fig. 1*a* at the A_3 transformation point in the neighbourhood of 920° C. The earlier results of Oberhoffer give no measure of the heat of transformation, only a measured value for total heat which seems to fit neither the curve above the transformation nor that below it. The earlier results of Umino show a discontinuity of the slope at the A_3 point but no discrete step in the curve.

The fact that Meliss's results are higher than Umino's would be consistent with the assumption that a greater error existed in Umino's work owing to radiation from the specimen in transit and from a loss of calorimetric fluid in the form of steam. However, Meliss did not publish his data in tabular form but as a curve of total heat against temperature without the plotted points being indicated. This curve shows no break at the A_3 position, nor even a discontinuity in slope, so that there is some doubt on the reliability of the results.

Jaeger, Rosenbohm, and Zuithoff, and Oberhoffer and Grosse, who used metal block calorimeters, have produced widely disagreeing results, yet both seem to have taken considerable care in the experimental technique. It may be noted that the greatest difference between the values of Jaeger and those of Wüst is between 2 and 3% at 900° C. Both these observers have investigated the enthalpy of pure platinum[63, 67, 68] and for this metal the agreement is better (greatest difference 1% at 100° C.). This suggests that some variation in the quality of the iron used by these observers may have been the reason for their obtaining different results, rather than the differing techniques employed. Owing to the disagreement between observers using the same type of calorimeter, it does not appear profitable to try to draw definite conclusions by comparing the results obtained by observers using different calorimetric methods.

To investigate variation in the purity of the various iron specimens as a possible source of disagreement, the composition, where given, is shown in Table II.

The analysis given by Adcock[69] applied to the pure iron used by Awbery, Pallister, and others whose results are tabulated in one publication.[65] The figure for the carbon content given by Adcock was not of the

Table II—ANALYSIS OF IRON SPECIMENS, %

Observer	Carbon	Silicon	Phosphorus	Sulphur	Manganese	Copper
Oberhoffer	0·06	0·005	0·005	0·019	0·05	...
Wüst, Meuthen, and Durrer	0·00	0·00	0·00	0·013	0·00	0·00
Oberhoffer and Grosse	0·02	0·006	0·006	0·004	trace	0·0
Umino (1926)	0·04	0·042	0·029	0·006	0·073	0·110
Meliss	0·06	trace	...	...	0·45	...
Adcock[69]	0·0005	0·002	0·00003	0·001	0·0003	0·001

same reliability as his other analyses and he was of the opinion that some revaluation of the standard methods of analysing for carbon was necessary. Later, Hopkins, Jenkins, and Stone[70] published a value of 0·002–0·004% for the carbon content of this pure iron sample. Baerlecken; Jaeger, Rosenbohm, and Zuithoff; and Umino in his 1929 work, state that electrolytic iron was used and give no details of composition.

The effect of these different elements on the thermal characteristics of iron is probably complex but not necessarily considerable. For instance, the only published measurement of the latent heat of fusion of a steel is 62·69 cal./g. found for a steel containing 4·04% of silicon, 0·07% of manganese, 0·04% of carbon, and 0·02% of sulphur by Oberhoffer and Grosse.[60] The same observers found 64·38 cal./g. for the latent heat of fusion of pure iron. The variation of the total heat at values of temperature up to about 1250° C. for pure iron and the silicon steel was of the same order but at higher temperatures the variation was greater.

Owing to the difficulty of obtaining pure iron, Oberhoffer and Meuthen,[71] with an ice calorimeter, and later Umino,[27] with a water calorimeter, attempted to obtain figures for the enthalpy of pure iron by measuring the enthalpies of various carbon steels and extrapolating to zero carbon concentration. Oberhoffer and Meuthen did not go above 650° C. and the results obtained by Umino were in close agreement with those he obtained in the same year for iron containing 0·04% of carbon; therefore these values have not been plotted in Fig. 1. In spite of the fact that the proportions of the other impurities in the metal varied in a random fashion between the various carbon steels, Umino obtained simple uncomplicated curves of total heat content against carbon content. An examination of the total heat content figures for various carbon steels obtained by Awbery and Snow[65] and Pallister[65] does not show a simple correlation between the total heat and the percentage of carbon.

Where the impurities present in iron are at a low concentration their effect in terms of the equivalent amount of iron displaced would be expected to be small. At transformation temperatures, however, the effect of impurities might be expected to be at a maximum, since the change in the internal structure of the metal is influenced by impurities. By this reasoning, it would be expected that the differences between the measured total heats for different iron specimens, if these do not depend on the different experimental techniques, would occur more at the points of transformation than at temperatures between the points of transformation.

In order to investigate this assumption, regression lines for total heats were calculated from the published results of selected observers for the ranges of temperatures between the A_3, A_4, and melting points. From these regression lines the values of the total heats at given temperatures were obtained and, as shown in Table III, the changes in total heats between the transition points were evaluated. Since the total-heat/temperature curve below the A_2 point is non-linear and since the A_2 point is not a true transformation point, the comparison is only made at temperatures above 900° C.

The figures in this table neither prove nor disprove the suggestion that any impurity in the iron has a maximum influence on the total heat measurement in the region of transformation.

There is a possibility that the total heat at a high temperature when measured by a sudden quenching may differ from that which would be obtained if a slow reduction of temperature were made. The crystal structure existing after a transformation depends on the rate at which the transformation occurred and various amounts of heat energy may be retained in the metal in other forms. The agreement between the two indirect measurements of total heat (Baerlecken and the N.P.L. results, *see* Fig. 1*b*) is very poor. Consequently, it is not possible to draw any conclusion by comparing the results obtained from a method involving a sudden reduction of temperature, as in the method of mixtures, with one involving slow temperature changes, as in the indirect methods.

At true transformation points the derivation of heat contents from specific-heat/temperature curves is difficult, since the specific heats become infinite. The direct method of Griffiths, Awbery and Snow, and others, however, allows a measurement of the latent heat involved in a transformation to be made experimentally. Austin[72] considers this to be a more accurate method of determination than that based on extrapolation of total-heat/temperature curves but he has ignored the fact that an extrapolation is still necessary because more heat than that actually needed in the transformation must be added to the specimen. Furthermore, the addition of sufficient heat to bring about a complete transformation will cause the annihilation and subsequent rebuilding of the temperature gradient in the specimen. Klinkhardt found the heat absorbed in the A_3 transformation in iron to be 3·86 cal./g. Unfortunately, the total heat figures for pure iron which are included in the publication[65] of all the N.P.L. measurements were not derived from the experimental data but from calculations based on the published figures of two separate investigators. The

two sets of available data covered different temperature ranges which joined at the neighbourhood of the A_3 point and, owing to this circumstance, the value for the heat involved in this transformation must be accepted with some reserve. However, the heat of transformation is given a value of 3·9 cal./g. in the original paper by Awbery and Griffiths.[45] The value of the heat of transformation at the A_3 point has been obtained at 6·67 cal./g. by Wüst, Meuthen, and Durrer[63]; 6·765 cal./g. by Oberhoffer and Grosse[60]; 5·60 cal./g. by Umino[62]; and 3·2 cal./g. by Jaeger, Rosenbohm, and Zuithoff[64] by calorimetry.

The Calculation of Latent Heats

The first determination of the latent heat of iron by means of the van't Hoff equation was made by Brisker[73] in 1908. Considering the iron–carbon system, he obtained a value of 31·6 cal./g. assuming carbon to be present in the diatomic molecular form, in order to bring his result into agreement with the experimental value then available for cast iron.

In 1929, this procedure was criticized by Ralston[74] who showed that, using the more accurate melting temperature then available and assuming that the carbon exists in the free elemental state in iron, the value of 57·5 cal./g. was obtained. However, Ralston pointed out that it was not known definitely whether or not the carbon existed in the form of Fe_3C in the iron, and he also showed that if the freezing point depression method was applied to the data on various metallic alloys of iron, given in the International Critical Tables, then a range of results from 44 to 112 cal./g. was obtainable.

Yap,[75] assuming that carbon is monatomic in solid iron and the solute Fe_3C is formed in molten iron, obtained the value of 64·2 cal./g. for the latent heat.

The whole position has been reviewed by Kelley[76] who states that only a few iron systems form a satisfactory basis for the calculation of the latent heat of fusion. The iron–carbon system is dismissed as unsuitable, but using the data of Isaac and Tammann[77] for iron–gold, that of Konstantinow[78] for iron–phosphorus, and that of Kurnakow and Konstantinow[79] for iron–antimony, Kelley obtained the values of 66·6, 65·5, and 67·7 cal./g. for the heat of fusion of iron. These three systems are the only satisfactory ones since, for others, the available data are insufficient or unreliable. The derived values are in fair agreement with the value 64·38 cal./g. obtained by Oberhoffer and Grosse using metal block calorimetry.

CONCLUSIONS

The most reliable values for the specific heat of pure iron over the temperature range from 0° to 100° C. are given by Griffiths's equation

$$S_t = 0{\cdot}1045\,(1 + 0{\cdot}001520t - 0{\cdot}00000617t^2)$$

where S_t is the true specific heat at a temperature t° C.

Table III—ENTHALPY OF IRON BETWEEN TRANSFORMATION POINTS, cal./g.

	Wüst, Meuthen, and Durrer[63]	Oberhoffer and Grosse[60]	Umino[62]	Meliss[59]	Jaeger, Rosenbohm, and Zuithoff[64]	Combined N.P.L. Data[65]
Total heat at 900° C. from Figs. 1*a*, 1*b*	141·6	150·0	139·6	152·5	144·6	140·0
Total heat at 950° C. by regression line	155·8	162·3	153·0	162·0	156·6	147·1
Change of total heat between 900° and 950° C., including A_3 transformation	14·2	12·3	13·4	9·5	12·0	7·1
Heat of transformation at A_3 point as quoted in published work	6·7	6·8	5·6	...	3·2	...
Total heat at 1350° C. by regression line	213·8	221·9	221·4	228·8	217·8	205·9
Change of total heat between 950° and 1350° C.	58·0	59·6	68·4	66·8	61·2	58·8
Total heat at 1420° C. by regression line	226·6	232·8	236·0	...	...	...
Change of total heat between 1350° and 1420° C., including A_4 transformation	12·8	10·9	14·6			
Heat of transformation at A_4 point as quoted in published work	1·9	2·5	1·9			
Total heat at 1520° C. by regression line	248·3	250·5	254·7			
Change of total heat between 1420° and 1520° C.	21·7	17·7	18·7			
Total heat at 1540° C. by regression line	301·1	317·8				
Change of total heat between 1520° and 1540° C., including latent heat of melting	52·8	67·3				
Total heat at 1640° C. by regression line	316·4	332·3				
Change of total heat between 1540° and 1640° C.	15·3	14·5				

At higher temperatures the following values are recommended after a survey of the published data.

Temperature, ° C.	True Specific Heat S_t	Temperature, ° C.	True Specific Heat S_t
100	0·114	700	0·221
200	0·124	A_2 755–760	0·276
300	0·132	800	0·204
400	0·143	900	0·173
500	0·160	1000	0·151
600	0·180		

It has been shown that owing to the wide variation in the experimental results obtained by the various observers, even when they employ similar methods of measurement, it is difficult to quote one or two observers as being the most reliable. Thus in order to obtain the best set of figures for the total heat contents of iron the only course would appear to be to take average results of selected observers, although this involves the assumption that the true result is a mean of the various experimental results. The derivation of the mean results has been made in the following way.

Of the nine observers, whose results are illustrated in Figs. 1 and 2, the results of Meliss[29] have been rejected, because his actual measurements are not available, and the figures quoted in the publication[65] of the full N.P.L. results have been replaced by the original figures published by Awbery and Challoner.[66] Also, Oberhoffer and Grosse[60] have been taken as superseding Oberhoffer,[59] and Umino[62] as superseding Umino,[61] where the two ranges of measurement overlap. The temperature range has been divided into the convenient portions bounded by the various points of transformation. From 0° C. up to the A_2 point the total-heat/temperature curve is non-linear but since over this temperature range the agreement between the various observers is closest, the mean curve has been obtained by drawing the best fit to all the plotted points. The A_3, A_4, and melting points have been taken to be 920°, 1400°, and 1530° C. since these temperatures correspond to the discontinuities in the curves obtained by the various observers. Assuming the portions of the total-heat/temperature curve between these points to be linear, the available data between each transformation has been compounded to give a single regression line. The A_2 point has been obtained as 770° C.—being the meeting point of the plotted curve from 0° C. and the regression line from 920° C. This is the temperature at which the change from the ferromagnetic to the paramagnetic condition is complete and is therefore above the value obtained in direct specific heat measurements which corresponds to the point where the maximum rate of change of specific heat occurs. The values for the total heat at selected temperatures obtained in this way are given in Table IV.

The reliability of the figures in the table becomes progressively less as the temperature increases but it is suggested that the figures may be accepted with some confidence up to the A_4 point at 1400° C. Between the A_4 point and the melting point only three sets of results have been used to obtain the regression line and above the melting point only one set, that of Oberhoffer and Grosse, has been accepted for the reason that this is the published set least subject to major criticism.

Table IV

AVERAGE FIGURES FOR THE TOTAL HEATS OF PURE IRON AT 50° C. TEMPERATURE INTERVALS

Temperature, ° C.	Total Heat, cal./g.	Temperature, ° C.	Total Heat, cal./g.
0	0	A_3 920	147·6*
50	5·5	A_3 920	153·4
100	11·2	950	157·9
150	17·2	1000	165·4
200	23·3	1050	172·9
250	29·6	1100	180·4
300	36·2	1150	187·9
350	43·1	1200	195·4
400	50·2	1250	202·9
450	57·7	1300	210·4
500	65·5	1350	217·9
550	73·7	A_4 1400	225·4†
600	82·4	A_4 1400	227·4
650	91·9	1450	237·5
700	102·3	1500	247·5
750	114·7	1530‡	253·5§
A_2 770	120·8	1530‡	316·4
800	126·2	1550	319·3
850	135·1	1600	326·5
900	144·1		

* Heat of transformation 5·8 ‡ Melting temperature
† Heat of transformation 2·0 § Heat of transformation 62·9

This procedure has resulted in a value for the heat of fusion which is slightly lower than that obtainable from the Oberhoffer and Grosse results alone. However, there is some doubt of the legitimacy of using the averaging method over this temperature range where an insufficient amount of data is available and it is here that more information, obtained by further measurements, would be most useful.

The temperatures at the transformation points are liable to be in error because in ordinary calorimetry the measurements are usually too dispersed to locate the points accurately. The values obtained by combining total heat data are therefore less accurate than values obtained by continuous temperature exploration. A combination of calorimetric determinations and thermal analysis would clarify the position.

The assumption of a linear relation between total heat and temperature above the A_2 point in the calculation of mean values leads to values for the mean specific heat as below.

Temperature Range, ° C.	Mean Specific Heat
770–920 (β-iron)	0·179
920–1400 (γ-iron)	0·150
1400–1530 (δ-iron)	0·201
1530–1600 (liquid iron)	0·145

Since A_2 is not a true transformation point and the effects of the loss of ferromagnetic properties extend over a range of temperature on either side of the temperature corresponding to the maximum effect, it is not unexpected that the recommended values for the true specific heat of β-iron do not agree with the mean specific heat given. The recommended true specific heat for 1000° C. is, however, in good agreement with the mean specific heat for γ-iron.

The measurements of the enthalpies for various steels are limited to the values obtained by Umino[27] for carbon steels up to 1250° C., by Oberhoffer and Grosse[60] for a 4% silicon steel including the melting

range, and to the values for various steels quoted in the collected N.P.L. data.[65] The latter were obtained by the indirect method from measurements of specific heats and do not include the melting range. In this field further direct experimental determinations of the total heats for different steels are necessary.

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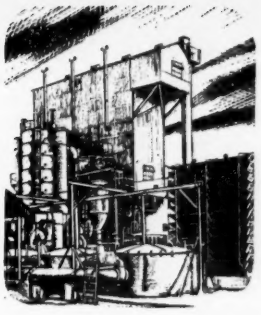
IRON AND STEELWORKS ENGINEERING

The Iron and Steel Engineers Group



THE IRON AND STEEL ENGINEERS GROUP

REPORT OF THE TWENTY-EIGHTH MEETING

The TWENTY-EIGHTH MEETING OF THE IRON AND STEEL ENGINEERS GROUP of The Iron and Steel Institute was held at the Institution of Electrical Engineers, Savoy Place, Victoria Embankment, London, W.C.2, on Wednesday, 23rd March, 1955. Mr. W. M. LARKE, Chairman of the Group, occupied the Chair.

At the MORNING SESSION, a paper by Captain (E) W. GREGSON, R.N.R., entitled "Some Comments on Waste-Heat Recovery Practice," was presented and discussed.

At the AFTERNOON SESSION, the paper presented and discussed was "Waste-Heat Recovery with Particular Reference to the Generation of Electric Power," by Mr. W. ERNEST, A.M.I.Mech.E. (which was published in the March issue of the *Journal*).

PROCEEDINGS OF THE MORNING SESSION: 10.30 A.M. to 12.45 P.M.

Some Comments on Waste-Heat Recovery Practice

By Captain (E) W. Gregson, R.N.R., M.Sc.(Eng.), M.I.Mech.E., M.I.Mar.E.

SYNOPSIS

The paper outlines the present state of the art of waste-heat recovery as applied to the steel industry and accents the requirements of a sound recovery system. These include avoidance of air infiltration in the flue system in order to afford the highest possible temperature gradient for the boiler unit. The use of economizers is discussed, and also draught control.

Reference is made to further possibilities of heat recovery, in particular from the sensible heat in molten blast-furnace slag and by dry coke quenching; it is suggested that present levels of fuel costs justify further investigations into the economics thereof.

Finally the use of the gas or air turbine is discussed—firstly for driving blast-furnace blowers, with regeneration of the exhaust heat as first-stage blast heating, and then to open-hearth furnaces, reheaters, and soaking pits. The author considers that waste-gas temperatures of 800° C. and above are desirable for some proposals, otherwise the resultant air temperature for the turbine falls below the economic limit. 1139

THE IRON AND STEEL industry is a thermal industry and fuel costs have always represented a major part of its production costs. If waste-heat recovery was justified when coal prices were 25% of what maintains today, the case for heat conservation is now more relevant than ever, although—over the same period—the cost of appropriate recovery equipment has advanced something like threefold. In addition, the need for fuel economy on a national level must be considered.

The idea of 'waste' is repugnant to the furnace builder, who, at all events 30 years ago, looked upon any suggestion of waste as a slur on his design genius. Likewise, the operator always reckoned that he could run his plant without waste. If the term 'surplus heat' had been used instead of waste heat the implied insult would have been avoided.

The idea was that there was just enough temperature in the reject gases of an open-hearth or reheating furnace to deal with draft requirements. Absence of

Captain Gregson is Chairman of Spencer-Bonecourt-Clarkson, Ltd.

instrumentation obscured the fact that base-of-stack temperature is no criterion of furnace efficiency; temperature can be reduced effectively by cold air infiltration into the system between the furnace and the stack.

The function of the open-hearth is to make steel: that of soaking pits and reheaters to keep ingot and semi-processed steel at appropriate temperatures for rolling sequences. Steam is a by-product and its generation must not in any way be detrimental to furnace operation. Furthermore, steel melting demands high furnace temperatures and accurate control of heat-application to avoid zoning; these factors can only be obtained by preheating the combustion air and, in certain cases, the fuels. The return of reject heat to the furnace in this manner is an operational necessity and also the simplest way of effecting fuel economy, as it calls only for additive equipment integral with the furnace itself. But there are limits to the range of effective regeneration, determined by gas : air : flue-gas ratios, and any attempts to abrogate the mathematical and physical laws which determine these limitations mean waste of regenerative/recuperative capacity. It is after effective recovery is applied that additive recovery by way of steam generation comes into consideration.

The objective of the designer who is concerned with purely waste-heat recovery is to maintain the gas flow at the highest possible temperature level by avoiding air infiltration and by adequate insulation. Air infiltration can become very troublesome in any system operating at sub-atmospheric pressures.

Waterlogged ground can be a source of heat loss and seepage of water into flues causes even greater losses, as it absorbs heat for evaporation.

Radiation and similar losses do not increase gas volumes, but air infiltration does—with the added nuisance of increasing the mass flow to be handled by the recovery plant.

On the formula for thermal efficiency $(T_1 - T_2)/T_1$, T_1 must be kept as high as practicable as T_2 cannot be controlled, being determined by steam conditions applying to the waste-heat boiler plant, or (where fitted) by the economizer. Whether economizers are fitted or not is determined purely on economic grounds (i.e. return on extra capital cost) coupled with space limitations, the latter being dominant in much of waste-heat recovery practice.

In a waste-heat boiler project, the purely boiler section can be visualized as a heat exchanger. Its arrangement of heating surface should be such as to get the best heat transmission possible by contact-effect between gas stream and tube surface, as the radiant heat absorption factor is low compared with that in fuel-fired boiler practice. The design should be as compact as possible commensurate with reasonable cleaning facilities, maintenance should be low, and as any waste-heat recovery scheme has to be finally assessed on return as capital invested, the simpler and cheaper the boiler design can be, the better. Much thought must be given in working out the details of a recovery scheme, such as the general question of handling the gases through the complete system together with many detailed items such as the positioning of superheaters to attain a reasonably steady steam temperature under varying conditions of gas temperature and mass flow, and also evaluating the most economic boiler draught drop by assessing operational cost against capital charges.

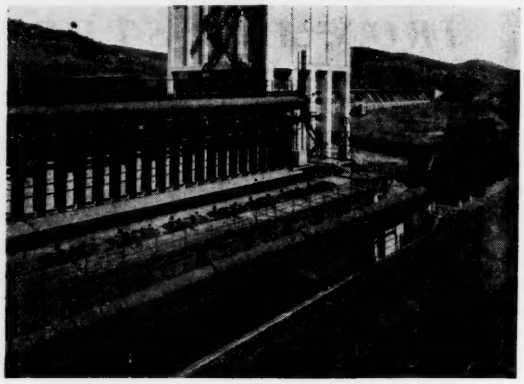


Fig. 1—Coke-quenching plant at Pretoria

Apart from boilers on forge furnaces and the like, the steel industry in its broadest sense has focused its attention as far as steam generation from waste heat is concerned on open-hearth furnaces, soaking pits, and reheating furnaces. Up to the late 'thirties these units were linked in to the existing works main and pressures seldom exceeded 160 lb./sq. in. with moderate superheat. The steam was used for the mill engines and for electric generation, together with ancillary requirements such as producers, etc. The shell type of boiler was almost standard practice and the storage capacity of a battery of these units was a distinct asset in levelling out supply and demand by the mill engines. The steam situation in the modern steel plant has been revolutionized by wholesale electrification, the mills now being operated by motorized units, and furthermore, the demand for even a modicum of steam for producers has disappeared where producer gas has been replaced by alternative fuels. This means that for new and modernized works steam is required almost solely for electric power production. A general increase in steam pressure and temperature is called for. Such a change, say 20 years ago, would have meant that the recovery units should now switch over to water-tube design in spite of their higher total cost per unit of heating surface—due largely to the high standard of casing work required to avoid air in-leakage. But the advent of the fusion welded technique of drum manufacture has resulted in the shell-type boiler still being appropriate to meet modern requirements.

Probably the most vital component in the waste-heat recovery link—especially in the open hearth, where accurate draught control is essential—is the fan unit. Where available, direct-current motors give simple speed control over a wide range, and in a few cases small geared turbines have been used, regenerating the exhaust steam by means of surface-type feed heaters and thereby giving a completely self-contained unit. (This practice is almost standard in the gas industry.)

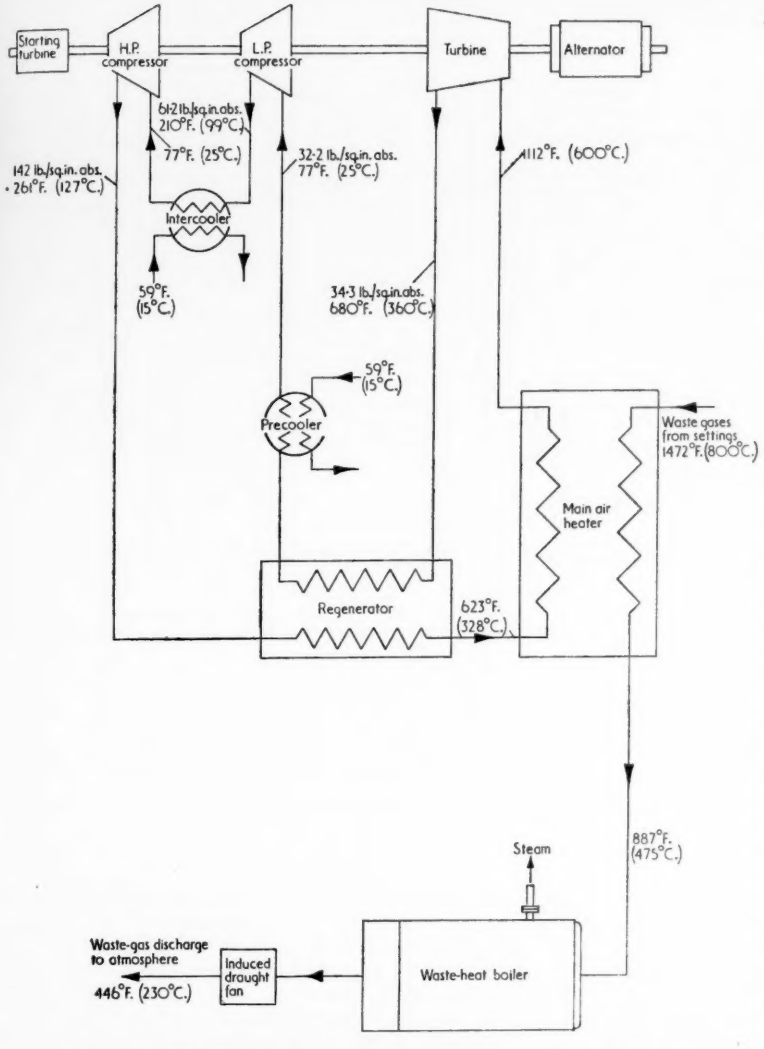


Fig. 2—Cycle diagram of Coventry waste-heat recovery plant

New plants are, however, tending to be all A.C. equipped. To avoid rather expensive multi-speed motors and control gear successful draught control has been obtained either by the use of the fluid coupling or by vane control in the fan itself. In such cases, in open-hearth practice, it is usual to fit a two-speed motor, bringing in the top speed when a higher level of draught is required to overcome increased resistance as the run of the furnace lengthens. Soaking pits and reheaters present simpler draught control problems, as the gas flow is non-cyclic and the gases are cleaner.

The limiting factor in all potential improvements is the economic one. A rearrangement of regenerators and waste-heat boilers to allow of the latter taking the reject gases first and then passing them to the regenerators while they still contain a sufficient heat gradient to deal with air preheat has attractions, as the boiler can then be much smaller as it will do most of its work by radiation—in fact it would really consist of a radiant tube screen. Alternatively, the hot gas stream could be split—one section direct to the boiler and one to the second-stage air preheater—the discharge from both sections then entering a primary air preheater which would follow more closely the orthodox lines of boiler air-heater practice. Two difficulties present themselves—potential slagging trouble in the boiler tube nest, and a complication of flue arrangements to allow the boiler to be by-passed in case of operational trouble and still allow the furnace to function.

In Germany progress has been made by steam-cooling those sections of the open-hearth furnace which are usually water-cooled. Instead of losing a considerable percentage of the total heat intake to the furnace diluted in a large volume of (often expensive) water, the steam yield resulting from the reduced flow increases the boiler output by 20%, without increasing either boiler or fan sizes. As the boiler is usually sited below furnace level, forced circulation for the cooling circuit is necessary but this can readily be added to a standard natural circulation unit.

It is a pity this idea cannot be extended, and instead of cooling outside the actual face of the furnace perimeter, a system of water walls incorporated which would be somewhat akin to a water-tube boiler furnace design. The effect in reduction of furnace maintenance would go far to revolutionize open-hearth practice but whether with high air/fuel preheat the necessary bath temperature would then be attainable is at present problematical. Of equal importance (assuming limited cooling) is the difficulty of avoiding unequal temperature zoning due to re-radiation to the ' black ' areas.

HEAT FROM SLAG

I believe Tees-side carried out some experiments on utilizing the heat in slag over 40 years ago. In the early experiment, the slag was water-quenched and the steam so generated at atmospheric pressures was led to an exhaust steam (condensing) turbine; a subsequent development incorporated an evaporator to give clean low-pressure steam for the prime mover. Allowing for losses in re-evaporation, 800–900 lb. of

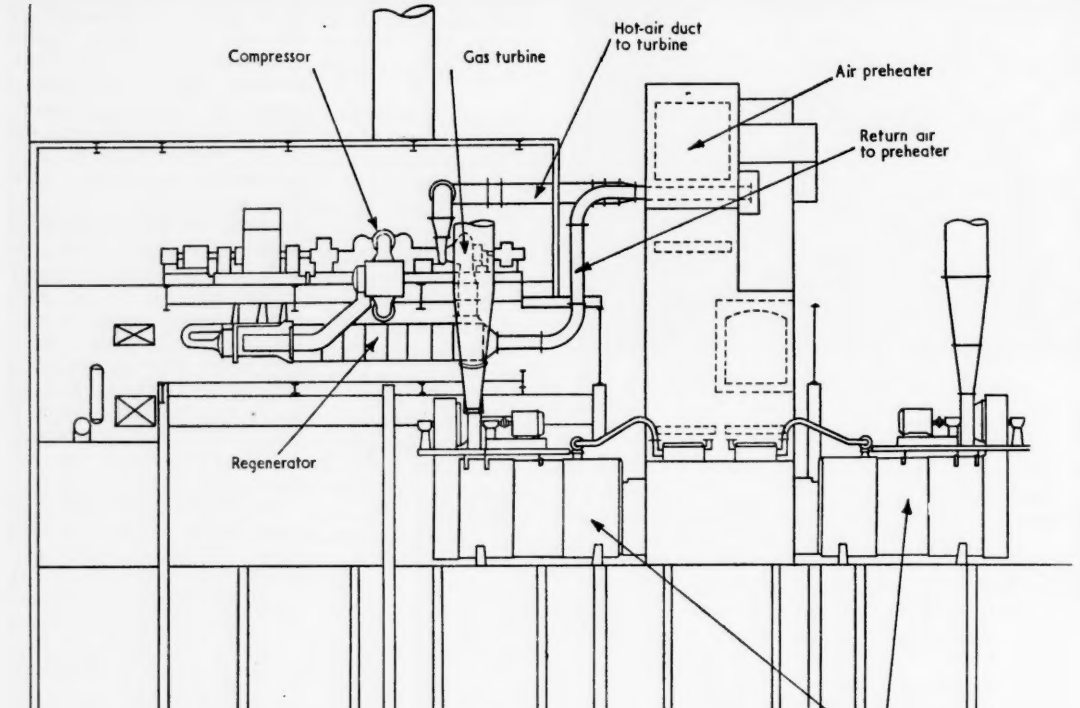


Fig. 3—Side elevation of Coventry waste-heat recovery plant

steam was available per ton of slag. The total heat in the slag amounted to about 11½% of the heat in the coke and the steam figure quoted above corresponds to about 5% of the original 'heat-in-coke.' Nothing further has matured beyond these experiments. The intermittent nature of steam production does not help matters, though if the steam is led as and when available to an existing mixed-pressure machine, this difficulty can be minimized. Blowing air through the molten slag has been tried by the author on a small scale, but local solidification upset the pattern of cooling and the experiments were unsuccessful. Some form of granulation by high-pressure air might avoid local blockages and keep a free passage at reasonably even resistance throughout the slag mass. The heated air would be exhausted through a conventional waste-heat boiler and so generate steam—rather on the lines of the cycle of a dry coke-quenching plant.

COKE QUENCHING

The mention of dry coke quenching focuses attention on another field for waste-heat recovery. Plants which have been installed for this operation produce a water-free coke (which should be an asset in blast-furnace work), and the absence of water entering the hot coke prevents disintegration due to steam formation. Coke is discharged at about 1000° C. and the dry quenching process yields 900–1000 lb. of steam per ton of coke. Obviously this is no mean source of power production, but in the past capital costs have been a deterrent to wider application. With present coal shortage—and coal prices—a re-survey of the whole situation is worth while. Incidentally, the amenity value of dry quenching is also an asset to any coke-oven plant. Figure 1 shows a C.O.L. coke-quenching plant installed at the South African Steel Company's coke-oven plant at Pretoria.

GAS TURBINE

The advent of the gas turbine has focused attention on the potential use of this prime mover in the iron and steel industry.

An attractive application at the moment appears to be as the motive unit for the blast-furnace blower, using blast-furnace gas. This, of course, is not a purely waste-heat recovery function. Its attraction over the usual arrangement of steam turbine-driven blower is the possibility of using the reject heat for partly pre-heating the blast. It is possible to visualize the replacement of the Cowper stoves by this system, using the turbine exhaust for the first stage of pre-heating and then topping up the temperature by auxiliary gas firing. A common compressor for both

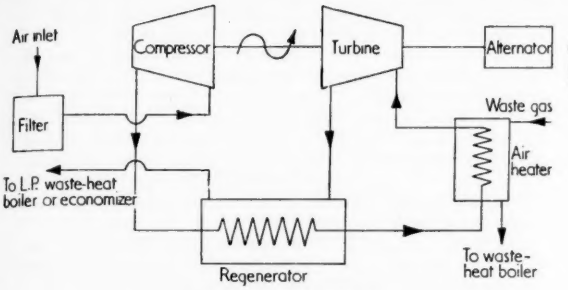


Fig. 4—Open cycle

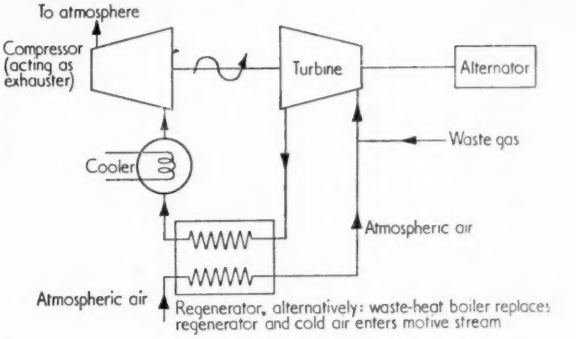


Fig. 6—Inverted cycle

the gas-turbine motive air and the blast air would effect great simplification in the power unit itself, but the balancing of pressure and volume requirements to meet both furnace and blower turbine requirements would not be easy.

The application of the gas or air turbine to industry was impracticable until compressor efficiencies were such as to reduce the negative work to an acceptable fraction of the gross power, and until the metallurgists could provide alloys at commercial prices which would enable the use of a turbine inlet temperature which offered an attractive cycle diagram. These difficulties have been overcome and the field of waste-heat recovery offers the gas turbine an application which is much simpler than that applying to fuel-fired units. There are no combustion problems and the waste gases do not have to pass through the turbine itself—i.e. the motive medium is (except in one system) clean compressed air heated in an appropriate air heater interposed in the waste gas flue system.

For a pioneer installation the carbonizing industry offered a more attractive field than iron and steel, as a gas turbine could be incorporated in a continuous vertical retort installation with the minimum of alteration to existing practice, and with the operational advantages of steady gas flow at a suitable temperature.

Two of the Companies the author serves are now jointly completing such an installation for the West Midlands Gas Board. Figure 2 shows in detail the cycle diagram of this plant, and Fig. 3 is a side elevation of the installation. The waste gas flow is derived from one of the installations of Glover-West continuous vertical retorts at Foleshill Gasworks, Coventry. Waste gas is available at 800° C. and in reasonably steady supply. This means that a moderately sized air preheater will enable the compressed

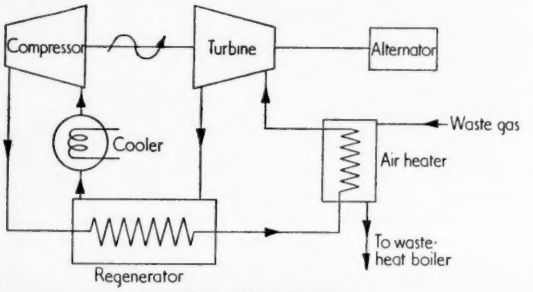


Fig. 5—Closed cycle

motive air of the turbine to be raised to 600° C. (1112° F.)—a figure below which the efficiency of the gas-turbine cycle falls rapidly. A demand for process steam allows the reject gases from the air preheater—at 475° C.—to generate steam at 120 lb./sq. in. in a conventional waste-heat boiler. The turbine is geared to a 700-kW. alternator and all current generated will link in to the general works supply: the closed cycle system (John-Brown–Escher-Wyss) has been chosen for this pioneer plant in order to ensure clean air through the turbine, compressor, and regenerator circuits. This enables a small-tube regenerator to be adopted to fit in better with site limitations, and the use of a pressurized circuit reduces the size of connecting pipework between the various components.

The compressor has two sections—centrifugal and axial—with inter-cooler, in order to attain high efficiency and so reduce negative work. Adoption of the closed-cycle system means that the turbine exhaust must be cooled down to as near atmospheric temperature as possible before re-entering the compressor. This could be effected by additional waste-heat boiler capacity plus after-cooler, but in the case of the Coventry installation full use can be made of the heated cooling water, hence an orthodox pre-cooler (before the compressor) has been adopted. In case of emergency the turbine can be shut down and the gas flow at full temperature by-passed direct to the waste-heat boiler, with enhanced steam yield. Starting up is effected by steam turbine and if desired this can continue in operation (using waste-heat boiler steam) to augment the power developed by the gas turbine, and incidentally produce some actual operational data on a combined gas–steam turbine cycle.

A gasworks with its carbonizing and ancillary plant normally calls for both power and process steam, and the choice for generation of the latter on a modern plant can be either by back pressure or pass-out steam from the power generating units, the bulk of the original steam coming from waste-heat boilers, or by a gas turbine combination on the pattern of that at Foleshill.

An iron and steel plant offers an entirely different problem as power is the end-product required from waste-heat recovery, there being no call for process steam beyond the by-product plant at the coke ovens. We have therefore a sizeable central generating

station which automatically means that higher pressure/temperature steam can be used effectively: in other words steam–electric generation has more to commend it than a multiplicity of comparatively small gas turbine units attached to each furnace. Incidentally, unless these machines run on D.C. there is the added complication of synchronization. There is a very attractive possibility for combined electricity/steam generation on a *large* installation of soaking pits or reheaters but the open hearth—with its cyclic variation in waste-gas flow and temperature—does not offer such an attractive case on present plant costs. If, however, the gas-turbine cycle is linked in with regeneration by preheating air for the furnace, the entire regenerative cycle can be re-cast and is a possibility worth exploring. Figures 4, 5, and 6 show in diagrammatic form the three possible cycles which lend themselves to the application of the gas turbine for waste-heat recovery.

It is not economic to operate a gas turbine with a temperature inlet of less than 600° C. (1112° F.) and this in turn—to get an economic heat transfer rate assessed against weight (and cost) of metal in the main air preheater—means a waste-gas temperature of 800–850° C. Split regeneration for furnace air preheating is therefore essential and in this case the ideas mentioned in the previous paragraph are relevant, as there are two sources of lower-grade heat available—the turbine exhaust (which is clean air and therefore suitable for direct combustion) and the reject heat from the gas turbine air preheater.

Discussion

Mr. **W. A. Johnson** (The United Steel Companies Ltd.): In opening the discussion I should like to say a word of thanks to Captain Gregson for filling a gap in our programme which exercised the minds of our Committee considerably. We are greatly obliged to him for doing so. He is a very old friend of mine, and I am delighted that he is here this morning.

The normal conception of efficiency—Captain Gregson speaks of $(T_1 - T_2)/T_1$—which can be applied to a simple mechanism or transmission, to a heat engine or any form of heat exchanger, is applicable to a large iron and steel plant taken as a whole. It has been said that the thermal efficiency of an iron and steel works is nil; it starts with all cold material and ends with all cold products.

In getting from the first of those cold states to the second we do two things. Firstly, we effect vast changes of state; for example, iron ore is converted into fine wire. Secondly, by way of balance there remains a good deal of energy of low potential, generally in the form of heat. The minimum amount of work to be done in transforming a piece of steel from state A to state B might be that represented by the area of a stress/strain curve if the operation were carried out on a piece of plant something like a tensile testing machine. The work expended in producing this result—that is, in altering a piece of steel from shape A to shape B—in any other way would be a measure of the efficiency of the method; it might, for instance, be done by rolling or by extrusion. It is interesting to contemplate how change of state processes can be carried out with the greatest efficiency so that the remnant balance of energy of low potential shall be as small as possible.

Captain Gregson has summarized various means of adorning and complicating open-hearth furnace plant. The open-hearth-furnace–waste-heat-boiler–fan-draught arrangement provides an increasingly useful and convenient combination. The high-temperature cooling of open-hearth furnaces has been described by Poppe (*Stahl u. Eisen*, 1953, vol. 73, Part 16, pp. 1030–1035), and Mr. McDonald has recently indicated (*J. Iron Steel Inst.*, 1954, vol. 176, pp. 71–92) what his firm have done and are doing in relation to economizers associated with their waste-heat boilers.

Each of these three systems shows a return on capital of the same order and augments steam supply at comparable steam cost. How far can we go? To that question there is no general answer. A notable external difference in appearance between a U.S. and a British steam locomotive is that the U.S. locomotive has a number of pipes on the outside, whereas the British locomotive either conceals them or dispenses with them. It might please Captain Gregson to adorn a waste-heat boiler with an economizer and with pipes leading to the open-hearth furnace doors and so on, but are we not in danger of ending up with something looking like a cross between a grapevine and an engineer's nightmare?

Whether we can use the steam which it often seems economic to produce is a factor to be related to the increasing electrification of rolling mills and other plant. This, of course, leads to the subject of Mr. Ernest's paper this afternoon and was what the Committee had in mind in this choice of subjects.

Considerable economy could be effected if something could be done about the recovery of heat from slag. Some plants which are smelting home ores make 25 cwt. of slag for every ton of iron produced. I have never yet heard, however, of a heat-recovery scheme which will appeal both to ironmakers and to engineers.

Mr. Pearson of Dagenham has written extensively on the recovery of sensible heat in coke (e.g. *Gas World*, 1947, Coking Section, vol. 126, 1st Feb., pp. 7–15) and in addition, Savage and Brancker have described (*J. Iron Steel Inst.*, 1949, vol. 161, pp. 103–117) the three commonly known types. The Dagenham system is the Sulzer bunker type; the second one, illustrated in Captain Gregson's paper (Fig. 1) is the C.O.L. multiple chamber type, and the third is the Sulzer unit chamber type. Why are they not in more common use? The full answer probably lies not in terms of a catalogue of detailed objections—dust nuisance, maintenance, the necessity for auxiliary plant, or the fact that if the coke is dry it might be sold too cheaply—but in the fact that relatively cheap steam is often more readily available in an integrated works. The major cost of a Sulzer bunker dry quenching plant would lie not in the boiler system but in the coke cooling chamber(s) and available capital today is generally directed to producing new necessities rather than to matters considered to be of more marginal value.

We have been interested in what Captain Gregson had to tell us about the development of gas turbines. Some of his conceptions are imaginative and well worth looking at, but very far removed from practical possibilities at the present time.

One point which has not been mentioned is that as sintering processes increase there is an increasing amount of heat lost as the sinter is cooled. It may be that some type of closed system could be used, as in coke quenching processes. The temperature range would be somewhat lower than in the case of coke so that larger boiler units would be needed. Where large quantities of sinter are being dealt with the plant cost would be high but other ways of using this large quantity of heat may be contemplated.

Mr. **F. Kennedy** (Dorman Long and Co., Ltd.): Some 30 years ago, I heard Captain Gregson give a paper on a somewhat similar subject and the fact that the opening part of today's paper covered much of the same ground emphasizes how little progress has been made in certain respects since then. The plant users in the steel industry may be partly at fault, but have the boiler manufacturers not been too satisfied with the comparatively simple fire-tube boiler? If one compares modern units with those 30 years old, there seems to be little real improvement. Viewing the installation of the waste-heat boiler as a means of saving coal, the heat-recovery equipment should be designed to generate the steam at the highest practicable pressure and superheat; very marked improvements could be effected by having a smaller boiler designed for higher pressures and fitted with economizers (possibly of the steaming type) with the superheater placed directly in the boiler inlet flue. This latter arrangement may tend to give varying superheats, but with a range of several boilers the final superheat temperature would not fluctuate greatly. This arrangement may be impracticable with producer-gas fired furnaces where a considerable quantity of live gas is burnt in the inlet flues at each reversal; on furnaces fired by oil and coke-oven gas, however, the maximum advantage would be obtained. This, of course, presupposes that the bulk of the steam is to be used for electricity generation and if any of the steam raised by the waste-heat boilers is to be used for process work, it could with advantage be passed out from the turbine after having done useful work in generating electricity.

With reference to the question of having a gas turbine in the waste-heat circuit, I would not consider it an economic proposition to have a comparatively small waste-heat boiler and gas-turbine installation to obtain a generation equivalent to a few hundred horse-power at each of a number of furnaces along an open-hearth plant. After all, the primary function of a steelworks is to make steel and the type of installation proposed would complicate the manufacturing process. Further, the capital cost, maintenance, and general operating efficiency would be much in favour of a single turbo alternator if steam conditions of 350 lb./sq. in. and 600° F. could be provided. In the example quoted by Captain Gregson, he was in the fortunate position of having a balanced demand for generated electricity, process steam, and hot water for process work, and high thermal efficiencies are possible, but this does appear to be an exceptional case.

Captain Gregson emphasizes one of the old bogeys of fuel inefficiency, i.e. air infiltration, which unfortunately has not yet been completely overcome. In most recent steelworks installations, however, air infiltration into the furnace chamber itself is much reduced by the practice of installing furnace pressure controls.

I can confirm Captain Gregson's comments regarding the desirability of the variable-speed motor drive as the tendency is for furnace capacities to be increased after initial installation and, therefore, the cautious designer always ensures that his boiler will be capable of taking a larger load than was originally anticipated. Further, provision must be made for blocking up of furnace checkers, etc., which increases the load on the fan. We have found that the installation of two-speed motors in conjunction with either hydraulic couplings or vane control has proved economically justifiable and has reduced appreciably the power consumption for the fan drive.

I strongly disagree with Captain Gregson's suggestion to fit the boiler immediately after the furnace because of the bad effect on the furnace efficiency. Maximum air preheat is vital for fuel efficiency and output at the furnace, and whilst fitting a boiler in such a position would raise more steam, this would be at the expense of the furnace, and Captain Gregson in his opening remarks accepted the proposition that the waste-heat recovery system should only be used to recover heat rejected from the main process. Anything which interferes with the efficiency of the primary unit inevitably has a bad effect on overall efficiency.

Similarly I am strongly opposed to his suggestion of water-walled furnaces if he has in mind anything similar to those used so successfully on boiler combustion chambers. In the open-hearth furnace the maximum temperature is required and the radiation effect from the brickwork on to the steel plays an important part in the efficiency of the heat transfer. A very long furnace life could be obtained by use of water-cooled walls, but only at the expense of steel output, and I think this suggestion would lead to loss of furnace output and efficiency.

The amount of heat which goes to waste in slag is appalling, but, on the other hand, direct quenching with water in order to obtain the heat will inevitably have a deleterious effect on the physical composition of the slag. As most iron manufacturers sell the slag, any potential heat recovery would be offset by the loss in slag credit, and I am afraid this will be one of the difficult problems left unsolved.

The question of dry coke-quenching is very attractive from the technical aspect but here again heavy capital expenditure is involved. The coke ovens and blast-furnace plants are already very highly capitalized, and the addition of a dry coke-quenching plant would greatly increase expenditure, with the probability that the installation costs would be still further increased by the necessity to instal dust extraction equipment.

With reference to the blast-furnace gas turbine, the effect of these on the blast-furnace gas distribution system must be borne in mind. In order to obtain optimum efficiency in an integrated steelworks, all the blast-furnace gas must be efficiently utilized and it is essential to have a suitable buffer unit to absorb fluctuations in gas availability without serious reduction in efficiency. The most convenient and efficient method of doing this is to use the boilers as the buffer in the blast-furnace gas system, and coke breeze, coal, and oil can all be used successfully as alternative fuels. If a blast-furnace gas fired turbine is installed in the system, this is a preferential consumer for gas and increases the difficulties in obtaining efficient fuel utilization.

Mr. **W. P. C. Ungoed** (Steel Company of Wales, Ltd.): Captain Gregson, in his paper, referred to a 'normal' waste-heat boiler, but the installation of waste-heat boilers on all sources of waste heat is far from being 'normal' practice. There are many works in the U.K. where only some of these heat sources are used for steam raising, and there are a greater number where there is no waste-heat recovery at all.

A national survey should be made, preferably by the Ministry of Fuel and Power, of all the unused sources of waste heat in this country. The results of such a survey, I believe, would show that there is a large potential total of steam for power generation and process capable of being raised in this manner without any additional fuel cost.

The waste-heat boiler is now well established as a perfectly satisfactory piece of apparatus, but it must be operated with the necessary technical skill, to give the best operating results. In the early days of waste-heat recovery, several installations fell into disrepute simply through the lack of appreciation of the tube cleaning and water treatment requirements. Today, technical

knowledge is far more widespread and the operation of this type of plant should present no insurmountable problem to an operating staff.

Captain Gregson gave a fair and accurate summary of the advantages and disadvantages of water-tube and smoke-tube types of boiler. From operating experience of both types of boiler, I would like to add that the water tube boiler can carry higher dust burdens in the flue gases, which is particularly important with the introduction of oxygen lancing on open-hearth furnaces and increases in the firing rates. A further advantage is that the water-tube type can operate at higher pressures than the 300 lb./sq. in. limit of the drum type, making possible the introduction of back-pressure generation in process steam supply.

The proposal to use a heat exchanger in the flue gas outlet of an open-hearth furnace, coupled with a closed-cycle gas turbine does not seem to be particularly desirable. Such a layout will depend very largely on the design gas flows and temperatures being maintained in practice. So many factors can vary these flue-gas conditions that the gas turbine will seldom be operating at its optimum efficiency. The waste-heat boiler is far more flexible in this respect.

The scheme of recovering the heat from open-hearth furnace door frames by steam raising is now receiving serious attention, in this country. Already, there are several pilot plants of this type operating in Germany and the Saar. As expected, there were 'teething' troubles in the design of the frame itself. The early door frames were excellent from the thermal conductivity point of view, but were mechanically weak, and could not stand up to normal rough usage. Later trials produced a door frame fabricated from a solid slab, which was not entirely satisfactory owing to cracking caused by differential thermal expansion. The present-day designs appear to be a good compromise between the mechanical and thermal requirements, and give satisfactory service. There will inevitably be some reluctance on the part of the melting shop managements to install this heat-recovery plant, possibly on the grounds of increased risk or additional down time, in exactly the same way as waste-heat boilers were objected to on their introduction. I see no reason why this recent proposal should not be as beneficial to open-hearth furnace operation and to the national fuel economy as its predecessor the waste-heat boiler.

Mr. **C. E. Sayer** (McLellan and Partners): What is Captain Gregson's opinion on the maximum pressure for which the shell-type boiler can be supplied, in sizes of 15,000–20,000 lb./hr., and what advances, if any, on present ideas on the subject are likely to take place ?

For fan drives the two-speed induction motor has had support both from Captain Gregson and from other speakers, but it possesses the disadvantage of the change-over in the operating range, and, as it is not easy to make the changeover automatic, it has to depend on manual operation and the human element in anticipating when it may be necessary. For cases where D.C. is not available, or where its availability cannot be permanently relied on, the variable-speed A.C. motors which can now be obtained have proved themselves, although expensive, entirely reliable, and I think they should be mentioned as an alternative method of dealing with this problem.

With reference to furnace waste-heat steam, is the author's factor of 1·2 for the door frames only, or does it include some water-wall arrangement as well ? Also, what is the authority for that figure ? There seem to be enormously varying ideas of what can be recovered in this way, and we can compare this factor of 1·2 with the figures in Mr. Ernest's paper, where in Table II he gives an addition of 28,000 lb./hr. on 77,000 lb./hr. —36%—and Mr. Ungoed mentioned an even larger figure.

I was interested to hear about the steam obtained from slag quenching in some experiments carried out a long time ago. I imagine that there is no such plant working in conjunction with a steam turbine working today and it would be interesting to know the reasons for dropping the experiments. Was it due merely to the impossibility of keeping any turbine blades in service for a reasonable period with this steam ?

In his reference to gas turbines Captain Gregson rather gave the impression that there was a sudden drop in their thermal efficiency below 600° C. inlet temperature. The higher the temperature the better from the point of view of efficiency, but although the fall in efficiency with reduction of inlet temperature is progressive at an increasing rate, no critical condition is reached at or about 600° C.

AUTHOR'S REPLY

Captain **Gregson**, replying to the discussion, said: Mr. Johnson has mentioned economizers operating in conjunction with waste-heat boilers. Their application depends on return on the additional capital involved and needs a case-to-case investigation. Where high steam pressures are involved, the temperature of the gases leaving the boiler (being determined by steam saturation temperature) reduces the extraction efficiency of the boiler section, hence in these instances a specially good case presents itself for economizers. Regarding Mr. Johnson's comments on heat recovery from the sintering process, capital cost assessed against steam yield has so far militated against recovery plant. The same refers to the Bessemer process where much heat is lost but I hope some day to be able to offer recovery plant which is appropriate.

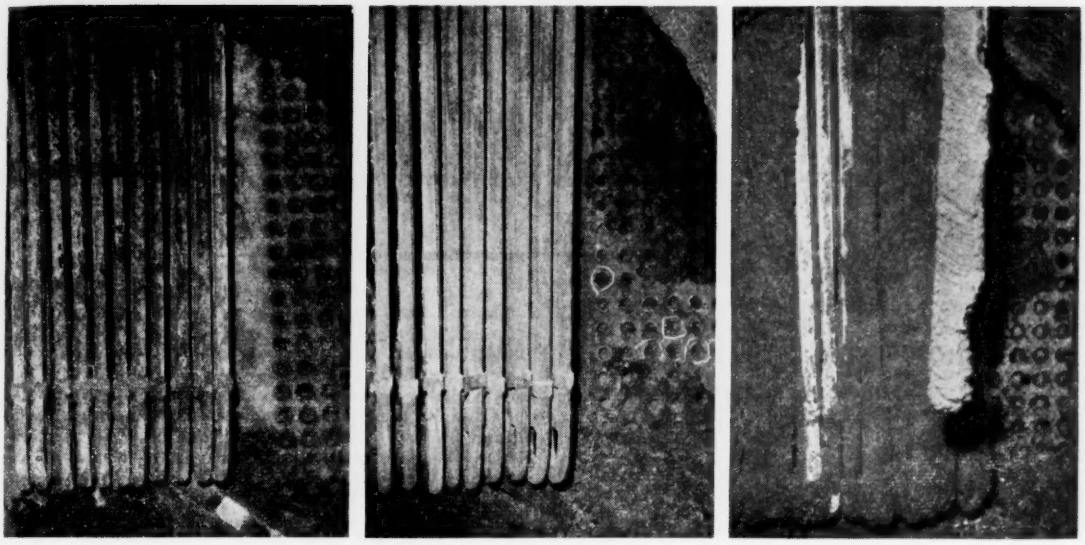
Mr. Kennedy refers to what appears to be lack of progress in waste-heat boiler technique, but much improvement in detail has been effected in the last 30 years—for instance, the use of fusion-welded drums for the high pressures, and some 30% increased efficiency in fans.

I am sorry I did not make myself clear on the subject of water-cooling the open-hearth furnace. It would indeed be a step forward if we could adopt water-cooling on the lines of a water-tube boiler furnace, but resultant lowering of temperature together with zoning make this impracticable for the open hearth in the present state of the art.

Referring to the gas turbine blower for blast-furnaces, my idea is to use the turbine exhaust for primary preheating and then top up to the required blast air temperature by auxiliary gas firing in an appropriate combustion chamber.

Mr. Ungoed referred to the relative merits of shell and water-tube designs of waste-heat boilers. The steam yield should be identical in either case, hence the choice rests on a number of factors such as site conditions, first cost, and maintenance costs. The shell boiler is no longer limited in pressure since the advent of the fusion-welded drum, but a real limitation is that imposed by rail/road transport. The shell boiler is lower in erection costs than water-tube designs as it is delivered on site in a fully fabricated condition—as far as the boiler section is concerned.

Mr. Sayer mentioned the two-speed fan motor: running at the lower speed meets normal conditions—in fact the fan unit is designed on these lines. The top speed allows a margin to cover requirements towards the end of the campaign of an open-hearth furnace, when the general state of regenerators, etc., calls for increased draught.



(i) At start of trial (ii) At end of trial (iii) Superheater not lanced

Fig. A—Waste-heat boiler superheater tubes

It is also a useful margin to have in hand to deal with potential increases in gas flow should the furnace to which it is attached be rebuilt at some future date on newer designs to increase output. Both Mr. Ungoed and Mr. Sayer commented on my figure for increased steam yield by the application of steam-cooling to certain sections of the furnace instead of using water. I know my figure is on the low side but I estimated on conservative lines as I do not want to 'gild the lily' in these early stages of this particular development.

The application of the gas turbine to the open hearth was mentioned by several speakers: owing to the comparatively low temperature head available, the cyclic gas flow, the outage periods of the furnace and the complexity of a series of small-power units it does not appear so attractive as when applied to larger units. If, however, we concentrate on air preheating instead of steam generation as the other component of the recovery cycle the study looks more hopeful.

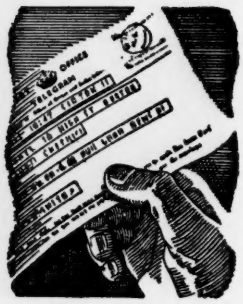
I fix approximately 800° C. as the lower gas limit for recovery by the gas turbine cycle as this allows for a turbine inlet temperature of some 600° C. without excessive heat-interchanger surface. With a T_1 at the turbine of less than this, the efficiency falls rapidly.

CORRESPONDENCE

Mr. **J. H. Flux** (United Steel Companies, Ltd.) wrote: When considering the installation of waste-heat boilers on steelmaking furnaces, Capt. Gregson has drawn attention to the importance of providing adequate cleaning facilities for the boiler tubes and also the importance of positioning the superheater so as to obtain maximum utilization of the heat in the waste gases. Often therefore, the superheater has to be positioned directly in the gas stream, with the result that the dust and slag carried by the waste gases are deposited on the nests of superheater tubes. The nature of this deposition depends to some extent on the type of scrap being melted, but having been deposited it becomes bonded to the tubes and cannot be removed by either air or steam blowing. The build-up is progressive, with a consequent drop in steam superheat temperature and it is necessary to take the boiler out of commission for manual cleaning, even though routine brushing of the boiler tubes has been effective as far as the boiler itself is concerned.

Recent trials carried out in conjunction with the Fuel Dept. of the Steel, Peech, and Tozer branch have shown that by water lancing the superheater of a waste-heat boiler attached to a 100-ton cold-charged open-hearth furnace, the tubes were kept clean for a prolonged period with an improvement of more than 100° F. in the steam superheat temperature. The essence of water lancing is the sudden chilling of the bonded deposit; the thermal stresses thus set up cause the deposit to fall off the tubes. For this trial the tubes were subjected to a jet of water at 130 lb./sq. in. pressure for approximately 10 sec. Figure *A* (i) shows the superheater after manual cleaning at the beginning of the trial and Fig. *A* (ii) after a 9 weeks trial with water lancing once a day. It is normal practice to take the superheat off for cleaning after 6–7 weeks and Fig. *A* (iii) shows such a superheater when lancing has not been practised.

The discussion at the Afternoon Session on Mr. Ernest's paper, will be published in a later issue of the Journal



N E W S

Announcements and News of Science and Industry

THE IRON AND STEEL INSTITUTE

Changes on Council

Mr. W. F. CARTWRIGHT has been elected a Vice-President and Mr. W. C. BELL a Member of the Council, of the Institute.

Mr. C. BRECKON, President of the Leeds Metallurgical Society, has accepted an invitation to serve as an Honorary Member of Council during his period of office, in succession to Mr. C. E. Burrell.

Special Meeting in Scunthorpe

As previously announced, a Special Meeting of The Iron and Steel Institute will be held in **Scunthorpe** from **Wednesday to Friday, 12th to 14th October, 1955,** by invitation of the Lincolnshire Iron and Steel Institute. The provisional programme of technical discussions and works visits was published in the May issue of the *Journal* (p. 66).

Autumn General Meeting, 1955

The **Autumn General Meeting** of The Iron and Steel Institute will be held on **Wednesday and Thursday, 16th and 17th November, 1955.** Full details of the programme will be given in a later issue of the *Journal*.

Annual General Meeting, 1956

Provisional arrangements have been made to hold the **Annual General Meeting** next year in London on **Wednesday and Thursday, 16th and 17th May, 1956.** The Members' Dinner will be held on the evening of Wednesday, 16th May.

NEWS OF MEMBERS

▶ Mr. N. S. CORNEY has been awarded the degree of Ph.D. of the University of London.

▶ Mr. C. G. DAVIES, formerly manager of the hot and cold sheet departments, and Mr. L. G. STOCK, formerly manager of the tinplate department, have been appointed Assistant Works Superintendents at the Ebbw Vale Works of Richard Thomas and Baldwins, Ltd.

▶ Capt. H. LEIGHTON DAVIES, C.B.E., Managing Director of the Steel Company of Wales Ltd. and a Past-President of The Iron and Steel Institute, is visiting Trinidad as a member of a board set up by H.M. Government to enquire into a dispute in the Trinidad oil industry.

▶ Mr. BENJAMIN FAIRLESS has retired from his appointment as Chairman of the Board of the United States Steel Corporation. He will continue to serve as a Director and a member of the Corporation's Finance Committee.

▶ Mr. S. L. FINCH has been appointed Joint Managing Director with Mr. A. H. CATTON and Mr. D. E. CATTON of Catton and Co., Ltd., Leeds. Mr. A. H. Catton remains Chairman of the Company.

▶ Mr. S. W. HORTON has relinquished his appointment as Chief Metallurgist to Bruntons (Musselburgh) Ltd. to become Works Manager to the Firth Co., Warrington.

▶ Dr. W. HUME-ROTHERY has been awarded the honorary degree of D.Sc. of the University of Manchester.

▶ The Hon. DAVID KIRKWOOD was created a Baron in the Birthday Honours List, and has assumed the title of Lord Kirkwood of Bearsden.

▶ Mr. H. S. SASTRI has taken up an appointment as Lecturer in Metallurgy in the Engineering Faculty of Rangoon University.

▶ Mr. COLIN SKINNER has left H.M. Forces and has joined Samuel Fox and Co., Ltd., as Technical Assistant to the Education Officer.

▶ Mr. R. C. WEIR has left the U.K. for Canada, where he has joined the Salem Engineering Co., Ltd., Toronto.

▶ Mr. W. J. WILLIAMS has left the British Cast Iron Research Association to become Chief Research Metallurgist to Midland Rollmakers Ltd., Crewe.

▶ Mr. E. WILLIS-JONES has joined the Cardiff office of Metropolitan-Vickers Electrical Co., Ltd.

Obituary

Mr. STANLEY G. DAVIES, of Scunthorpe.

Mr. JOHN CHESTER SIMON, formerly Chairman of the Cast Iron Axle Box Association, on 6th March, 1954, aged 74.

CONTRIBUTOR TO THE JOURNAL

Captain (E) W. Gregson, R.N.R., M.Sc.(Eng.), M.I.C.E., M.I.Mech.E., M.I.Mar.E.—Manager and Chief Engineer of the Marine Division of Babcock and Wilcox Ltd., and Chairman and Technical Director of Spencer-Bonecourt-Clarkson Ltd. (until recently Spencer-Bonecourt Ltd.), a subsidiary of Babcock and Wilcox Ltd. specializing in waste-heat recovery.

Captain Gregson served his apprenticeship in Monmouthshire and received his technical training at the University College of South Wales and Monmouthshire at Cardiff.

A Director of West's Gas Improvement Co., Ltd., of Manchester, Captain Gregson is also a Past President of the Institution of Mechanical Engineers, and represents that body on the Council of the Institute of Fuel, of which he is a member.

IRON AND STEEL ENGINEERS GROUP

Meeting of Junior Engineers, 1955

A Meeting of Junior Engineers will be held in London from **Monday to Thursday, 26th to 29th September.** During the afternoon of Monday Mr. F. Starkey will present his paper on "*Guides, Rods, and Strippers for*

Modern Bar Mills " for discussion, and there will also be a lecture on the Corby Works of Stewarts and Lloyds Ltd.

On Tuesday, there will be an all-day visit to the Ford Motor Company Ltd., at Dagenham, and on Wednesday an all-day visit to Stewarts and Lloyds Ltd., at Corby.

On the Tuesday evening there will be a Dinner at the Rembrandt Hotel.

A lecture by Mr. Sven Fornander, Director of Research of Jernkontoret, on the Swedish Iron and Steel Industry has been arranged for the morning of Thursday, the 29th.

Engineers Group Meeting

A half-day meeting of the Engineers Group will be held at the Engineers' Club, Manchester, on the morning of **Thursday, 20th October,** in connection with the National Fuel Efficiency Exhibition. Dr. W. S. Walker of Round Oak Steel Works Ltd. will present a paper for discussion on " *Fuel Efficiency in the Iron and Steel Industry.*"

Notices about these meetings will be sent to Members in due course.

BRITISH IRON AND STEEL RESEARCH ASSOCIATION

Forty-Fourth Steelmaking Conference

The subject of the 44th Steelmaking Conference held by B.I.S.R.A. at Ashorne Hill, near Leamington Spa, on 4th and 5th May, 1955, was " *Recent Developments in Instruments and Measuring Techniques for Steelmaking Furnaces.*" The Conference attracted an unusually large audience and, judging from the discussions, the subject was of great interest. The chair was taken by Mr. R. W. Evans, and Mr. W. C. Heselwood acted as Vice-Chairman.

The use of Pitot-tube and radon-tracer techniques for the measurement of air and waste-gas flows in open-hearth furnace systems were described by Mr. D. Thomas and Mr. D. Meachen respectively. Judging from the papers given and from the subsequent discussion, it was evident that the difficult problem of measuring air flows in furnace systems has been overcome. The Pitot tube technique is a straightforward procedure in a furnace with a generous flue system providing suitable sites for surveys, but it is unsuitable for valve leakage measurements or for use in the vicinity of bends in the system. Fortunately the radon tracer method, although a little more complicated to set up, can be used independent of furnace construction at a particular point, and is thus suitable for valve leakage measurements. The modifications made to this technique during the last few years have resulted in a relatively simple procedure for the rapid determination of flows by using very low concentrations of radon. This makes it an inexpensive and safe method. Further simplification of the technique was foreshadowed by Mr. Meachen.

Air temperature measurement, usually required in conjunction with flow measurements, was reviewed by Mr. T. Land, who dealt mainly with the new B.I.S.R.A. suction pyrometer. He emphasized the high degree of accuracy of this instrument for open-hearth preheat temperature measurement and its ability to maintain this accuracy under the severe conditions of open-hearth furnaces for relatively long periods. Mr. R. Mayorcas then described the twin thermopile radiation pyrometer for the measurement of flame and gas temperatures. The discussion, as well as dealing with the details of the measuring techniques, also provided some interesting information about the level of open-hearth preheat and waste-gas temperatures and volumes at various works and their relation to productivity. There was considerable discussion on the use of a paramagnetic oxygen meter and on the value of routine measurement of the waste-gas flow for combustion and preheat control.

On the following day, a description was given by Mr. C. Burns of the B.I.S.R.A. furnace periscope, and this was followed by a spectacular film taken by means of this instrument of the interior of an open-hearth furnace at frequent intervals throughout two charges. Mr. C. H. Bacon who took the film, gave a very interesting commentary on it. This film is to form the basis of a documentary feature about the periscope.

During the last session of the Conference, the Vice-Chairman gave a statement on the present position of the development by a panel appointed by the British Standards Institution on which B.I.S.R.A. is represented of a new blue glass for furnacemen's goggles. The aim of the work is that the new blue glass should fulfil these requirements: (1) to provide protection for the eye from harmful infra-red radiation; (2) to allow sufficient transmission of red as well as blue to facilitate temperature assessment by change of shade as well as by change of intensity; (3) to be reproducible from melt to melt so that an exact replacement of a broken lens is possible without the melter being obliged to accustom himself to another shade of blue. An experimental glass has been made and is at present being tried out by melters in various parts of the country.

Temperature measurement of furnace roofs and walls by means of thermocouples was described by Mr. J. A. Hall, who showed that this was an accurate method of measurement over relatively long periods that would be sufficient for investigational purposes. During the discussion, it transpired that there was some possibility of using thermocouples for the routine measurement of furnace roof and wall temperature, but that this would depend largely on the severity of the conditions in the furnace and the development of more suitable refractory sheaths.

Recently developed instruments and measuring techniques that had been described during the sessions were exhibited in a room adjacent to the Conference Hall and attracted a great deal of attention between sessions and immediately after the end of the Conference talks.

Eighth Junior Blast-Furnace Conference

The Eighth Junior Blast-Furnace Conference was held at Harrogate on 25th and 26th May, 1955. The Chair was taken by Dr. H. L. Riley, and during the Sessions the proceedings were under the guidance of two Vice-Chairmen, Mr. J. Lockerbie and Mr. T. Myers.

After an introductory statement by the Chairman, the Conference began with the subject of increased iron-making capacity at Appleby-Frodingham. Two papers were presented; the first by Mr. B. L. Robertson gave details of the ' Apex ' and the more recently installed ' Seraphim ' ore-preparation plants. The ' Seraphim ' sinter machines were described, and the differing features of the ' Apex ' machines were explained. Reference was also made to various methods adopted to obtain control of the sintering process to provide a consistent product. The second paper presented by Mr. N. Haslam described the development of the blast-furnaces from several small units up to the four large ones now at South Works. The constructional details of the Queen Victoria furnace were described, together with a description of ancillary equipment and the important features of the cast-house layout.

At the second session, Dr. H. R. Lahr presented a paper discussing the various types of refractories, their characteristics in relation to their use in various parts of the furnace, and the changes, both physical and chemical, which have been made in the manufacture of

refractories during the past 10 years. This was followed by a description by Mr. J. G. Yaxley of the methods employed in the construction of a blast-furnace lining.

Subjects directly concerned with blast-furnace operation and practice were considered by four Discussion Groups during the following session. The elected Chairman of each group then reported back to the full Conference at a subsequent session. This enabled members to comment on aspects which were not the subject of their own Group.

The final session was devoted to a review by members of the Divisional Staff of current research projects concerned with blast-furnace probes and statistical analysis. An explanation of the use of ternary and quaternary diagrams to obtain optimum slag compositions was also given.

Extensive discussion took place during the major sessions and was summarized in the closing remarks of the Chairman.

AFFILIATED LOCAL SOCIETIES

Swansea and District Metallurgical Society

The following is the list of Officers for the Session 1955–56:

President
R. W. EVANS, M.Met.

Vice-Presidents
R. WALKER
J. S. CASWELL, M.Sc., M.I.Mech.E., A.M.I.C.E.

Hon. Secretary
M. J. A. THOMAS, B.Sc.

Hon. Treasurer
L. A. S. PERRETT, F.I.M.

Members of Council
H. A. COOKE (*Chairman*)
A. J. K. HONEYMAN, B.Sc., A.R.T.C., F.I.M.
Dr. R. HIGGINS, O.B.E., F.I.M.
D. A. BISHOP, A.I.M.
D. W. HOPKINS, M.Sc.
R. G. DAVIES
R. L. WILLIAMS
R. J. THOMAS, A.I.M.
S. S. CARLISLE
W. R. HITCHINGS
J. HEY

EDUCATION

Whitworth Scholarships

The Minister of Education, as Trustee of the Sir Joseph Whitworth Foundation, has decided to increase the maximum number of Senior Scholarships awarded from 2 to 3, and to increase their value from £325 to £500 p.a. These awards will be available for post-graduate work, and will be known as Whitworth Fellowships. A number of Whitworth Prizes of greater value than previously will be awarded to unsuccessful but meritorious candidates for Fellowships. The award of ordinary Whitworth Scholarships will be discontinued.

These changes, which will operate from 1956, have been made as a result of the increased number of maintenance allowances and scholarships granted to students and the greater need for post-graduate awards. A leaflet setting out the new regulations governing the Whitworth awards has been published, and copies are available from H.M.S.O. or through any bookseller, price 3*d*. each.

NEWS OF SCIENCE AND INDUSTRY

Société de Chimie Industrielle—Meeting in Madrid

The twenty-eighth International Congress of Industrial Chemistry will be held by the Société de Chimie Industrielle in Madrid on **22nd–31st October, 1955.** The Congress will be divided into 23 sections, and the programme will include works visits in Madrid and in neighbouring districts.

Société de Chimie Physique—Meeting in Paris

The sixth Annual Meeting of the Société de Chimie Physique will be held in Paris on **22nd–25th May, 1956,** when the main subject for discussion will be "*Surface Reactions of Gases on Metals.*" Further details of the meeting are obtainable from the Secretary-General at 10 rue Vauquelin, Paris, 5.

Institution of Mining and Metallurgy

The Gold Medal of the Institution of Mining and Metallurgy has been awarded to Emeritus Professor W. R. Jones, C.B.E., in recognition of his services to the science of economic geology and to the Institution, of which he is a Past-President.

The Rt. Hon. Sir Winston Churchill, K.G., O.M., C.H., has accepted Honorary Membership of the Institution, which has also been conferred on Mr. G. A. Denny in recognition of distinguished services to the mining industry in South Africa, and on Dr. J. B. Tyrell in recognition of his work in the exploration and development of the mineral resources of Canada.

Birmingham University Metallurgical Society

The Birmingham University Metallurgical Society celebrates its Golden Jubilee anniversary this year, and in recognition of this anniversary a special enlarged edition of the Society's magazine is being produced. Former members of the Society may obtain a free copy of the special edition on application to the Editor of the Society at the Metallurgical Department, The University, Edgbaston, Birmingham, 15.

Institute of Fuel

The Annual Luncheon of the Institute of Fuel was held on Thursday, 28th April, 1955, at the Connaught Rooms, Great Queen Street, London, W.C.2. Dr. W. Idris Jones, C.B.E., President of the Institute, was in the Chair, and the principal guest was Mr. C. M. Vignoles, O.B.E., Chairman of the Petroleum Industry Advisory Council and Managing Director of Shell Mex and B.P. Ltd. Mr. Vignoles spoke of the increasing use of oil as a fuel; coal had entered a phase of relative decline, and, together with power generated by atomic energy, oil must become increasingly important. It was already being used extensively in the provision of subsidiary fuels and petroleum gases, the partial conversion of the railways to diesel power, and in specialized industrial processes. In the steel industry, over 1½ million tons of oil were used per year in the U.K., although there were no oil-fired O.H. furnaces in the country until 1945. Mr. Vignoles looked forward to a future of close co-operation between the oil industry and the fuel-consuming industries to effect greater technical and economic advantages.

Protection of Structural Steel

A symposium on the protection of structural steel was held in London on 31st March–1st April, 1955. Dr. J. C. Hudson, Head of the Corrosion Section of B.I.S.R.A., acted as Chairman, and particular interest was shown in the relative merits of paint and metal spraying, and methods of testing in various countries. The meeting also included the Spring Lecture of the Society of Chemical Industry, which was delivered by Mr. F. L. La Que of the International Nickel Corporation (U.S.A.).

Conference for Junior Employees

A weekend conference for apprentices and junior operatives from all the works of the Company was held

by The United Steel Companies, Ltd., on 15th–18th April, 1955. The theme of the Conference, which was held in conjunction with the Industrial Welfare Society, was "*Responsibility*."

Need for Research on Ore Treatment

The need for a national institute for research on ore treatment was stressed by Sir Harold Hartley in his Presidential Address to the Institution of Chemical Engineers on 26th April. The recovery of metals from low-grade ores was of increasing importance to modern industry, and research into extraction metallurgy and mechanical ore treatment should be undertaken by a national organization.

File Trades Research Council

A File Trades Research Council has been set up in Sheffield with the approval of the D.S.I.R. The Council, which will be run on the same lines as the Cutlery Research Council, will assist in solving manufacturers' problems and will aid the file trade in general; so far about 40 firms have decided to give their support. A research team will be housed in the Sheffield Laboratories of the British Iron and Steel Research Association and will work in conjunction with the Steel Users' Section of B.I.S.R.A., under the supervision of Mr. C. N. Kington.

Nuclear Energy Conference

An organization to aid British industrial development of nuclear energy has been set up by the Institutions of Civil, Mechanical, Electrical, and Chemical Engineers, and the Institute of Physics. It is hoped that a symposium on the technology of nuclear energy and its applications will be held in the autumn of this year. Sir Christopher Hinton, Managing Director of the Industrial Group of the Atomic Energy Authority, will be Chairman of the organization.

Undersea Drilling for Coal

The first attempt in Great Britain to prove undersea coal by drilling at sea is being made by the National Coal Board. A specially designed tower has been constructed and floated, from which drilling will be carried out, and the boring site chosen for this attempt is near Kirkcaldy, Fife, in the Firth of Forth.

Industrial Publications Received

▶ Brochure on 'Heurtane' producers and cleaning plant—Gibbons Heurtey Ltd.

▶ A fully-illustrated 52-page publication on 'Colclad' steels gives information on the manufacture, properties, and fabrication of stainless, nickel, and Monel clad steels—Colvilles Ltd.

▶ Brochure on 'Visco' air conditioning and fume removal for steelworks—Publication No. 551—Visco Engineering Co., Ltd.

▶ A fully-illustrated 16-page brochure published by George Kent Ltd. gives details of the Company's range of products for the measurement of water, steam, gas, oil and petrol, temperature, conditions, etc., and of developments in the field of automatic process control. The Company has also published a brochure (ref. 361) on the 'Commander KU' flow meter for measurement by differential pressure.

▶ A Buyers' Guide prepared by the British Gear Manufacturers' Association includes an index to the manufacturers of principal types of gears and gear units, and gives in detail the range of products manufactured by each of the member firms of the Association.

▶ Booklet on the Hilger metal ratio analyser—Hilger and Watts Ltd.

▶ Pamphlet on the preservation and protection of all types of structures, roofs, felt, metal, etc.—Pamphlet No. M-14—Andrew Maxwell (Liverpool Borax Co., Ltd.). Copies of the leaflet are available free on application to the Company.

▶ Quartz crystal X-ray goniometer for industrial or laboratory testing of cut crystals—Publication No. CH 381/2: Miniature X-ray diffraction cameras—Publication No. CH 382. Hilger and Watts Ltd.

▶ Brochure on 'Closeloy' precision-made rolls—Armstrong Whitworth (Metal Industries) Ltd.

▶ Brochure on drying plant, electric heating, evaporators, laboratory and pilot plant, metal pickling plant, etc.—Publication No. 282/A: Continuous neutralization plant for use in the pickling of steel—Publication No. 295. Kestner Evaporator and Engineering Co., Ltd.

▶ The Spring, 1955, edition of "*Bakelite Progress*" includes details of the use of 'Bakelite' resins for foundry shell moulds and cores.

▶ "*Guide to Industrial Lubrication*" lists over 300 grades of lubricating oils and greases manufactured by Alexander Duckham and Co., Ltd.

Changes of Address

DEMAG ELEKTROMETALLURGIE GmbH. has removed to new premises in the Haus der Konstrukteure, Wolfgang-Reuter-Platz, Duisburg, Germany.

RHODEN PARTNERS LTD. have removed to new premises at 51 North Row, London, W.1 (Tel. Mayfair 6248).

CORRIGENDUM

Metastability of Austenite in an 18/8 Cr–Ni Alloy

In the paper by Dr. B. Cina, published in the March, 1955, issue of the *Journal*, the captions to Figs. 7 and 8 (p. 232) should read as follows:

Fig. 7—Effect of tempering at (*a*) 500°, (*b*) 600°, (*c*) 700°, and (*d*) 800° C. on the constitution of an 18/8 Cr–Ni alloy at room temperature

Fig. 8—Thermomagnetic changes in an unstable 18/8 Cr–Ni alloy: (*a*) 1st heating, (*b*) 1st cooling, (*c*) 2nd heating, (*d*) 2nd cooling

TRANSLATION SERVICE

(The previous announcement was made in the July, 1955, issue of the *Journal*, p. 300.)

TRANSLATIONS AVAILABLE

No. 503 (German). E. LÖBBECKE: "Lining of Basic Cupolas. A Critical Review of the Literature on Present State of Development of Basic and Neutral Refractories, the Possibilities of Using Them with or without Coolers in the Cupola." (*Giesserei*, 1954, vol. 41, Sept. 16, pp. 477–485).

No. 504 (Swedish). G. WALLQUIST: "Calculation of Roll Pressure and Energy Consumption in Hot Rolling." (*Jernkontorets Annaler*, 1954, vol. 138, No. 9, pp. 539–570).

CHARGES FOR COPIES OF TRANSLATIONS—The charge for translations is £1 for the first copy and 10*s*. for each additional copy of the same translation. Requests should be accompanied by a remittance. These translations are not available on loan from the Joint Library.

TRANSLATIONS PREPARED AT MEMBERS' REQUESTS—Members requiring translations of foreign papers are invited to communicate with the Secretary, who will ascertain whether they can be prepared for inclusion in the Series.

ABSTRACTS OF CURRENT LITERATURE AND BOOK NOTICES

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MINERAL RESOURCES

Exploitation of Norwegian Ore Resources. H. Dahl. (*Tek. Ukeblad*, 1955, **102**, Feb. 24, 158–164). [In Norwegian]. The author discusses the historical background of Norwegian ore mining, mechanization, level of capital investments, wages, personnel, cost of research, and economic results.—G. G. K.

Iron Mining by the Companhia Vale do Rio Doce in the Itabira District, Minas Gerais, Brazil. C. Effenberger. (*Eng. Min. e Met.*, 1954, **20**, Sept., 129–134). [In English]. An account is given of the geology of the Itabira iron-ore deposits, which consist of hematite in a host rock known as itabirite. The ore is mined by open-cast methods and an account is given of the crushing and screening sequence in the ore-dressing plant. Screen and chemical analyses of the prepared ore are given.—D. J. O. B.

Deposits of Manganese Ore in India. N. Dekowski. (*Z. Erz. u. Metal.*, 1954, **7**, Nov., 488–494). Manganese ore deposits in India are surveyed, giving outlines of geology, mineralogy, and mining methods. Some production and cost data are quoted.—E. C.

ORES—MINING AND TREATMENT

Pelletizing of Iron Ore Fines Using Pyrrhotite as Binders. T. Morimune and M. Ikeda. (*Tetsu to Hagane*, 1954, **40**, Dec., 1101–1106). [In Japanese]. Pellets prepared in various ways were tested for compressive strength, specific gravity, porosity and analysis, and by dropping. High-strength pellets were produced using 5–10% pyrrhotite as binder, the heating temperature being 150–200° C. lower than usual. The sulphur content was $< 0{\cdot}1\%$. Pyrrhotite was better than limonite as a binder, and led to reduced agglomeration costs.—K. E. J.

Beneficiation of Iron Ores with and without Chemical Reactions. W. Luyken. (*Rev. Tech. Luxembourg.*, 1954, **46**, Oct.-Dec., 248–257). [In German]. New results obtained with heavy-medium separation of Salzgitter and Siegerland ores are given. The beneficiation of taconites and European minette ores is discussed. The problems of grinding ores to a high degree of fineness and of agglomerating the enriched portions are considered.—B. G. B.

Trials on Desulphurization and Use in the Blast-Furnace of Barytic Khénifra Ore. C. G. Thibaut and J. Astier. (*Publ. Inst. Rech. Sid.*, Série **A**, 1954, (83), Nov., 138 pp.). After an historical survey concerning Khénifra ore, results of agglomeration trials at Sidi-Marouf are quoted. The amount of sulphur in the ore is reduced 81% during agglomeration, and the mechanism of the process is discussed. In blast-furnace trials at the Boucau works, a campaign using Khénifra agglomerate was compared with normal running. It appears that the barytic slag containing 15% BaO removes more sulphur than normal slag. Appendices contain full results, and a description of plant used in the trials.—T. E. D.

The Constitution of Iron Ore Sinters and the Mechanism of their Agglomeration. J. A. Boned Sopena. (*Inst. Hierro Acero*, 1954, **7**, Oct.-Dec., 393–414). [In Spanish]. The relationship of sinters to their original constituents (Vivero and Sierra Menera ores) is illustrated in a mineralogical study. The mechanism of sintering was examined by a microradiographic technique (on Grängesberg ore) and the influence of coke, lime, and free silica upon the processes is reported. (15 references).—P. S.

A Test to Determine Sinter Quality. W. Küntscher and J. Holzhey. (*Met. u. Giesserei Techn.*, 1954, **4**, Oct., 435–439). An apparatus and method for determining the reducibility of sinter are described and the results obtained are discussed. The test was designed to facilitate the control of the operation of sintering plant.—L. J. L.

FUEL—PREPARATION, PROPERTIES, AND USES

Waste Gas Analyses for Combustion Control. C. G. Rosenbohm. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1954, **37**, 297–301). The author describes the use of waste-gas analyses for combustion control at the Keystone Steel and Wire Co. The positions and times at which samples are taken are indicated, and the interpretation of the results is discussed. The benefits obtained from the practice are given.—G. F.

Heat Transfer by Radiation. J. H. McGuire. (*Fire Research Special Report No.* 2, 1953: D.S.I.R. and Fire Offices' Committee). Expressions are derived by which the radiation intensity at a point, due to various shapes of heated surface (e.g. disc, sphere, rectangle), may be computed. The expressions are concerned only with the relative geometry of the surface and are known as ' configuration factors.' The properties of these factors are listed, and expressions are derived for the radiative heat transfer between surfaces when multiple reflections can occur. (17 references).—L. E. W.

The Calculation of Gas and Surface Radiation in Furnaces, and of Flame Temperature Distributions. P. H. Price. (*Sheffield Univ. Fuel Soc. J.*, 1954, **5**, 40–46). A method of calculating gas radiation and flame temperature, based on subdividing the flame and combustion chamber, is presented. The necessary physical and geometric factors for radiation from, through, and to the subdivisions are found. Lack of data at present prevents the method being applied with confidence to the design of furnaces and combustion chambers.

Metallic Recuperators and Industrial Furnace Recuperation. L. S. Brown. (*J. Inst. Fuel*, 1954, **27**, Nov., 556–559). The scope of modern metallic recuperators is defined. Waste-gas temperatures up to 1300° C. can be expected to preheat air up to 750° C. and fuel gas up to 400° C. Performance curves are given for various conditions, and the influence of operating variables on plant cost is examined.—D. L. C. P.

Escher Recuperator in Industrial Applications. H. Escher. (*Commonwealth Eng.*, 1954, **41**, July 1, 479–483). The design of this waste-heat recuperator and its suitability for high-temperature furnaces are discussed, and its utilization with soaking pits, forging furnaces, continuous heating furnaces, melting furnaces, and foundry cupolas is described.—J. E. J.

The Determination of Heat Losses through Compound Walls. K. Leitner. (*Radex Rundschau*, 1954, (3), Apr., 95–100). An account is given of Heiligenstaedt's method of calculating the rate of heat flow through walls composed of layers of different thermal conductivities.—E. C.

The Selective and Petrographic Preparation of Coal from the Point of View of Coking. E. Burstlein. (*Chaleur et Ind.*, 1954, **35**, Dec., 351–370; 1955, **36**, Jan., 14–28). The required properties of metallurgical coke are stated. These include uniformity of texture within the coke and constant properties with time. An increase in productivity of coke ovens is also necessary to reduce the price of coke. Standardization of the size index after abrasion testing is suggested. The effect of coal size on coke properties is surveyed, and the influence of petrographic constituents is also discussed. Details are given of the Longwy-Burstlein process, which eliminates segregation and gives a uniform product. The importance of mixing of the coke-oven charge and control of moisture is emphasized. The effect of density of oven charge on productivity is discussed, and density of charge is plotted against moisture and fineness. Operating data for classic and improved coking practice are compared, and costs are estimated.—T. E. D.

Industrial Metal Detectors with Special Reference to Sorting of Ores and Coal. T. G. Charles. (*I.V.A.*, 1954, **25**, (5), 209–220). [In English]. Details are given of the design and performance of a new ASEA tramp iron detector, and of quantitative measurements on ores possible by slightly modifying the equipment. Practical applications of metal detectors, choice of coil size, and operating frequency are also dealt with.

Effect of Hot-water Quenching on Coke. J. W. Thomas. (*Amer. Inst. Min. Met. Eng., Proc. Blast Furn., Coke Oven, Raw Mat. Comm.*, 1954, **13**, 96–106). The author gives results of tests comparing hot-water and cold-water quenching of coke, indicating that the former has the following benefits: lower and more uniform moisture in coke; more uniform and complete cooling, with decreased quenching time; decreased amount of fines; fewer belt burns; cleaner coke; and easier screening of residual sizes. The procedure adopted at Hamilton Works of the Steel Co. of Canada Ltd. is described.—G. F.

Special Study of Sulphur Removal and Recovery from Fuels. (*Inst. Fuel, Inaugural Conf. at Inst. Mech. Eng.*, Oct. 6–7, 1954). This study was directed and limited to an examination into possible methods of removing and recovering sulphur from fuels before combustion. The papers presented include:

The Social and Industrial Consequences of the Presence of Sulphur in Fuels. A. Parker. (5–10). The need for a greater recovery of sulphur from fuels is emphasized. The pollution of the atmosphere and its detrimental effects on the public health are discussed, and methods of sulphur removal from waste gases are described.—E. A. C.

Sulphur Removal from Fuel Gases by Dry Methods. R. H. Griffith. (48–58). The chemistry of the iron oxide dry purification process is described, with a brief reference to the development of artificial purifying materials to replace bog ore. (26 references).—E. A. C.

Methods for the Wet Purification of Coke-Oven Gas, Using Ammonia Liquor. H. Schäfer. (66–70). The author gives an account of experiences with ammonia scrubbing plants in Germany. The Kittel scrubber is described. A system used at the Gneisenau coke-oven plant consists of two bubble towers, with a circulation system consisting of a condenser and a pressure de-acidifier; its advantages are described. Details are also given of the Pauling system in operation at the Nordstern coke-oven plant.—E. A. C.

Desulphurization of Coke-Oven Gas by Selective Quick Washing with Ammonia Solution and the Conversion of Hydrogen Sulphide to Sulphur, Sulphuric Acid or Ammonium Sulphate. H. Bähr. (71–76). A description of the chemical basis of the ammonia process leads to a definition of the selective quick washing process, and a description is given of the basic requirements of a washing plant and the ammonia solutions to be used. The application of this process to coke-oven practice is considered. (23 references).

Experiences in the Operation of a Collin Desulphurizing Plant. T. H. Williams. (77–83). The Collin process for the desulphurization of coke-oven gas is used at the Corby coke ovens. The chemical basis of the process is outlined, and a detailed description is given of the plant and some modifications to combat corrosion. Operation and control are discussed, and operating data and analyses of gases and liquors for the gas-washing plant are included.—E. A. C.

Removal of Hydrogen Sulphide from Producer and Other Industrial Gases. A. J. Brockwell and F. F. Rixon. (84–91). A description is given of the wet purification processes for the removal of hydrogen sulphide from producer gas and other industrial gases. Other processes for the selective absorption of hydrogen sulphide are also described. The production of sulphur and sulphuric acid from hydrogen sulphide is discussed. (25 references).—E. A. C.

[Abstracts of other papers will be found in their appropriate sections.]

REFRACTORY MATERIALS

Review of Refractory Products Made in the Electric Furnace. A. Paoloni. (*J. Four. Elect.*, 1954, **63**, May-June, 79–81; July-Aug., 115–117; Nov.-Dec., 183–186; 1955, **64**, Jan.-Feb., 23–26). The production and properties of a wide range of refractory materials made in the electric-arc furnace are described. The refractories include fused silica, fused alumina, fused magnesia, fused zirconia, silicon carbide, boron carbide, electro-cast magnesia, aluminium silicates, magnesium silicates, zirconium silicate, spinels, aluminous cement, and graphite.—B. G. B.

Forsterite Refractories from Indigenous Magnesium Silicate Rocks. M. R. Rao and R. Singh. (*J. Sci. Indust. Res.*, 1954, **13**B, Nov., 805–811). A mineralogical study, including roasting with and without magnesite, of some Bihar minerals indicates their relative suitability for manufacturing forsterite refractories. A low-chromium serpentine (Cr_2O_3, 1½%) has been found suitable with an addition of 30% magnesite, while a higher-chromium serpentine (Cr_2O_3, 8%) and a saxonite, requiring additions of 25% and 45% magnesite respectively, are less satisfactory. The optimum firing temperature is 1500° C.—J. O. L.

Control Testing of Open Hearth Refractories. W. J. Scharfenaker. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1954, **37**, 153–155). The author briefly describes the procedure adopted at the Dearborn plant of Ford Motor Co. for routine control testing of refractories.—G. F.

Deformation Under Load at 2000° to 2500° F. and Silicate Liquid Absorption in Basic Brick. T. F. Berry, J. C. Ekedahl, and R. B. Snow. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1954, **37**, 128–145). The authors discuss the results of investigations of some of the high-temperature properties of basic bricks. Fired basic brick is shown to be more volume-stable to liquid silicate penetration than chemically bonded brick. Load-test data show that initial subsidence in both types may occur in the range 2100–2400° F. under loads of 6–50 lb./sq. in. Simulative wall tests show that a fired brick may crack 2–3 in. behind the hot face under a load of 25 lb./sq. in. when heated to 2900 F.; one type of chemically bonded brick did not crack under similar conditions, apparently because they deform under load without creep below 1800° F. The application of the results is discussed.—G. F.

The Refractoriness of Some Types of Quartz and Quartzite. Part I. F. Sandford and S. Fransson. (*Acta Polytechn.*, 1954, **4**, (3), 1–27). The refractoriness of quartz under a compressive load of 0·5 kg./sq. cm. was determined from the linear expansion of test pieces heated at 50° C./min. up to 1100° C. and thence at 10° C./min. to the softening temperatures. The transformation of α-quartz (M.P. 1600° C.) to α-cristobalite (M.P. 1713° C.) is accelerated by Si_2O, K_2O, Na_2O, MgO, CaO, Cr_2O_3, Fe_2O_3, or FeO and retarded by Al_2O_3 and to a lesser extent by TiO_2. Large additions of KNaO or small amounts of Al_2O_3 decrease, while Cr_2O_3 increases the refractoriness under compressive load.—E. C. S.

The Degeneration during Service of Basic Refractories. F. Trojer. (*Radex Rundschau*, 1954, (6), Aug., 214–224). Results are given of detailed microscopic studies of used basic bricks from open-hearth furnaces. Phenomena of recrystallization, replacement, pick-up of solids and liquids, and surface conditions are discussed.—E. C.

Developments in Steel Plant Refractories. L. A. McGill and J. A. Pierce. (*Amer. Ceram. Soc. Bull.*, 1954, **33**, Nov., 328–331). The fundamental properties of the various types of basic refractory materials and of silica brick are reviewed, together with their use in steel-melting and processing furnaces. The different types of basic brick and their application are discussed. Super-duty silica bricks allow many operating advantages when compared with conventional quality brick in open-hearth furnace roofs.—D. L. C. P.

BLAST-FURNACE PRACTICE AND PRODUCTION OF PIG-IRON

The Sulzer 7500-kW. Blast-Furnace-Gas Turbines Under Construction for the Hainaut Steel Works. E. Aguet. (*Rev. Univ. Min.*, 1954, Series 9, **10**, Dec., 724–734). A description is given of the design of these turbines, which are for generation of electricity and blowing air to the blast-furnaces. The advantages of this type of design are considered.—B. G. B.

Coke and Iron Service. Report of Activities During 1949 to 1952. (*Publ. Inst. Rech. Sid.*, Série **B**, 1953, (23), Nov., 26 pp.). Brief reports are given on the following IRSID investigations: Manufacture of metallurgical coke, properties of cokes and coals, blast-furnace practice with various cokes, proportion of fine ore that can be used in a blast-furnace, general blast-furnace practice, ancillary plant, and the low-shaft blast-furnace.—T. E. D.

Burdening of Blast Furnaces with Iron-bearing Materials Commonly Used in the Great Lakes Region. J. F. Peters and K. Neustaetter. (*Amer. Inst. Min. Met. Eng., Proc. Blast Furn., Coke Oven, Raw Mat. Comm.*, 1954, **13**, 12–28). The authors discuss in detail the burdening problems encountered with Inland Steel Co.'s blast-furnaces, quoting production and test data, and put forward the burdening principles adopted from their experience. The chemical and physical principles and their interaction are first considered, and it is shown how changes in the burden can bring about substantial changes in production rate.—G. F.

Improvements in Pig-Iron Casting on the Pig Casting Machine at the VEB Eisenwerke West at Calbe (Saale). H.-J. Lux. (*Met. u. Giesserei Techn.*, 1954, **4**, Oct., 446–449). The new pig-casting machine at the Calbe steelworks is described and steps taken to overcome teething problems are discussed. By reducing the freezing speed in the pans the spongy layer on the surface was eliminated; the hardness of the pig iron was noticeably reduced, and larger amounts of graphite separated out.—L. J. L.

Sulphur in Coke and Its Effects on Iron Production. A. Stirling. (*Inst. Fuel, Inaugural Conf. at Inst. Mech. Eng.*, Oct. 6–7, 1954, 10–22). Details are given of the sulphur content of British cokes, and the effect of sulphur on iron production is discussed. The advantages of desulphurization by the sintering process are emphasized. The desulphurization potential of blast-furnace slags is considered in detail. Particulars are given of the practice at Corby for desulphurization after the blast-furnace, and a comparison is made with the Kalling process. (57 references).—E. A. C.

More Furnaces Resort to Pressurised Operation. (*Steel*, 1954, **135**, Sept. 20, 128–131). The advantages and extent of high-top-pressure operation of blast-furnaces are briefly recounted. In the U.S.A. there are 13 licensed pressurized furnaces; in U.S.S.R., 11 are reported.—D. L. C. P.

Blast Heat in Modern Practice on Easily Reduced Material. D. M. Morrison. (*Amer. Inst. Min. Met. Eng., Proc. Blast Furn., Coke Oven., Raw Mat. Comm.*, 1954, **13**, 163–169). The author discusses the effect of blast temperature in blast-furnace practice when using an easily reducible burden. High blast temperature in such practice is shown to be detrimental in general, and moderate or low blast temperatures give the best results.—G. F.

Desulphurization of Pig Iron with Solid Lime. H. L. Saunders, V. Giedroyc, and T. E. Dancy. (*Amer. Inst. Min. Met. Eng., Proc. Blast Furn., Coke Oven, Raw Mat. Comm.*, 1954, **13**, 29–35). The authors discuss the laboratory development and works trials of a process for desulphurizing pig iron, involving mixing the iron in a ladle with lime-coated coke. The results obtained are quoted, showing that lime is at least equal in performance to soda ash as used in many plants, without producing the deleterious, highly fluid slag.—G. F.

Blast Furnace Slag-metal Reactions. J. Chipman. (*Amer. Inst. Min. Met. Eng., Proc. Blast Furn., Coke Oven, Raw Mat. Comm.*, 1954, **13**, 193–207). The author reviews recent laboratory studies which aid the understanding of the final stage of iron-ore reduction and the reactions occurring near and below the tuyere zone of the blast-furnace. The factors considered are: the solubility of carbon in liquid iron; the reduction of iron, manganese, and silicon; the occurrence of silicon carbide and other silicon compounds; and the desulphurizing power of the slag.—G. F.

Topochemical Aspects of Iron Ore Reduction. G. Bitsianes and T. L. Joseph. (*Amer. Inst. Min. Met. Eng., Proc. Blast Furn., Coke Oven, Raw Mat. Comm.*, 1954, **13**, 179–193). The authors have investigated the reduction of six types of iron ore of different origin, composition, and physical structure, and show that the normal course of gaseous reduction follows a topochemical behaviour. Four deviations from this behaviour, related to cracking, porosity, impurities, and residual oxide phases, are described. The effect of wüstite retention on the rate of magnetite reduction is discussed, and the differences in the rates of magnetite and hematite reduction are considered.—G. F.

TREATMENT AND USE OF SLAGS

Trace Elements in Processed Blast-Furnace Slag [Hüttenkalk] of Physiological Importance to Plants. A. Schmid. (*Hüttenwerk Oberhausen A.G., Technische Berichte*, 1951/54, Paper No. 18).

Conversion of the Slag–Cement Brick Plant from the Air to the Steam-Hardening Process. G. Mussgnug. (*Hüttenwerk Oberhausen A.G., Technische Berichte*, 1951/54, Paper No. 16) The conversion of the Oberhausen plant for the manufacture of slag–cement brick from the air- to the steam-hardening process showed a substantial increase in production, by improved mechanization, an improvement in porosity, and a reduction in the sulphur content of the brick.—L. D. H.

DIRECT PROCESSES

Trials on the Direct Reduction of Soumont Ore (Normandy) in the Laramie (Wyoming, U.S.) Rotary Kiln. J. Astier. (*Publ. Inst. Rech. Sid.*, Série **A**, 1954, (63), June, 260 pp.). A series of trials carried out by the U.S. Bureau of Mines in conjunction with IRSID is comprehensively described. The Bureau of Mines pilot plant at Laramie is described in detail, and operating data from both the small and large rotary kilns are tabulated. Methods of magnetic separation and of testing the products are outlined, and many photomicrographs of the sponge are shown.—T. E. D.

A New Way from Ore to Steel. H. Hofmeister and C. Herrmann. (*Demag News*, 1954, (136), 1–6). A short account of the Stürzelberg process for producing pig iron and the subsequent manufacture of steel in the lance-blown convertor is given. In the Stürzelberg process reduction of the iron ore to metal takes place in a reverberatory furnace after a preliminary heating in a revolving kiln furnace. It is economical if the iron content is $> 40\%$ and the silica content $< 12\%$. Very pure pig iron can be produced.—B. G. B.

PRODUCTION OF STEEL

Reconstruction of O.H. Steelworks of "Hüttenwerk Salzgitter A.G." Voigt. (*Demag News*, 1954, (137), 2–15). A detailed illustrated account of the reconstruction of this O.H. steelworks is given. The three furnaces have a capacity of 150 tons each and are of the tilting type. Steel is produced from pig iron containing phosphorus. A maximum of 75% pig iron in the charge has been used; the iron contains 2·8–3% P, and 0·7–1·0% Si. The rate of production averages 12·5–14·5 tons/hr. of molten steel. Blown metal from the adjacent Bessemer steelworks is also used in the charge.—B. G. B.

The Work of the British Iron and Steel Research Association on Subjects Associated with Fuel Research. A. H. Leckie and L. H. W. Savage. (*Sheffield Univ. Fuel Soc. J.*, 1954, **5**, 7–14). The main projects described include the following subjects: (1) Ironmaking—sinter-plant operation, study and control of blast-furnace burden distribution; (2) steelmaking (O.H. furnaces)—size of flues and uptakes, flame radiation and

burner design, port design, measurements on furnaces; and (3) heating steel for rolling—cooling of ingots in the mould, operation of soaking pits, flow of ingots between melting shop and mill, reheating furnaces and flame behaviour.—D. L. C. P.

American Adaptations of the Austrian Oxygen Converter Process. W. C. Rueckel and W. A. Vogt. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1954, **37**, 239–251). The authors give a brief account of the development of the "L–D" oxygen converter process and of the results obtained in Austria, and discuss how the process can best be adapted to U.S. methods and conditions.—G. F.

Contribution to the Study of the Role of Manganese in Refining in a Basic-Bessemer Converter. M. Cassier, P. Leroy, and J. Stremsdoerfer. (*Publ. Inst. Rech. Sid.*, Série **A**, 1954, (77), Sept., 36 pp.). Over 400 casts produced in Thomas converters in three different works were examined. Data concerning the processes in each of the works are given. Composition of the charge, conditions of manufacture, and chemical characteristics of the final metal are correlated. Behaviour of the ingots when they were rolled is also examined. The results are interpreted statistically.—T. E. D.

Rammed Acid Open Hearth Bottoms. H. C. Bigge. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1954, **37**, 91–98). The author discusses the requirements of acid O.H. bottom material and illustrates the design and construction of a furnace bottom. The method of installation is also described, details being given of the heating cycle and sintering operation.—G. F.

The Maerz Type of Suspended Roof. F. Bartu. (*Radex Rundschau*, 1954, (6), Aug., 203–205). A suspended type of roof design is described and compared with arch and ribbed roofs. Great advantages are claimed in initial cost, installation, and maintenance.—E. C.

Cleaning of Open Hearth Waste Gases by Kaiser Steel Corporation, California. B. N. Dagan. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1954, **37**, 72–78). Details are given of an electrostatic precipitator in use at the Kaiser Steel Corporation. The modifications made to it and the results obtained in practice are reviewed.—G. F.

Cleaning of Open Hearth Waste Gases at Fairless Works. H. A. Parker. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1954, **37**, 69–71). Open-hearth waste gases at Fairless Works, United States Steel Co., are cleaned by electrostatic precipitators, two to each furnace. The design of the plant and the routine practice and maintenance adopted are outlined.—G. F.

Tapping Double Heats at Sparrows Point. J. H. Kelley. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1954, **37**, 66–67). At Sparrows Point plant of Bethlehem Steel Co., five 380-ton furnaces have bifurcated launders and are tapped into two ladles, even filling being obtained by means of a stopper rod at the dividing nose.—G. F.

A Statistical Approach to Melt-in Control. S. F. Elam and F. E. Williams. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1954, **37**, 42–53). The authors discuss the problem of 'melt-in control' or the maintenance of a proper balance between the elements to be oxidized and the oxygen input in steelmaking, and present a procedure for the development and application of a simplified control method.—G. F.

Control of Melt Carbon and Working Heat. A. M. Kroner. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1954, **37**, 284–288). The author outlines the system adopted at Inland Steel Co. for controlling the melt carbon and the working of the heat in the O.H. furnaces. The aspects discussed include charging, bottom and bank maintenance, firing, slag flushing, refining, and temperature control.—G. F.

Charging and Fluxing Practices in Cold-metal Shops Using Burnt Lime and Low Percentage of Pig Iron. S. L. Fredericks. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1954, **37**, 310–313). The author reviews the results of a questionnaire submitted to U.S. cold-metal shops using burnt lime and low iron charges. Attention is given mainly to charging practice, pig iron additions, lime additions, and fluxing practices.—G. F.

Quality Control with Low Iron Charges. H. W. Potter. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1954, **37**, 301–309). The Lukens Steel Co. operates fixed 135-ton basic O.H. furnaces with 30% cold-metal charges. The melting and teeming practices are outlined and brief details are given of the quality-control precautions, with particular reference to sulphur and residual elements.—G. F.

Recent Uses of Open-Hearth Automation. R. A. Lambert. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1954, **37**, 274–284). The author describes some of the recent automatic-control devices installed at the Pittsburgh Works of Jones and Laughlin Steel Corp. to improve production and increase O.H. furnace life. The main controls are those for roof temperature, furnace pressure, and fuel/air ratio. Training of the personnel is also outlined.—G. F.

Boils and Furnace Bottoms. G. R. Fitterer. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1954, **37**, 111–122). The author lists the different types of boiling actions and, with special reference to acid O.H. practice, discusses their nature. The factors considered include volatile metal impurities; the start of the carbon boil and means of sustaining it; oxygen level and the effect of bottom condition; local boiling on inserted rods; bottom boils; and reboiling.—G. F.

Importance of Manganese in Steelmaking. F. W. Luerssen and P. H. Smith. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1954, **37**, 180–186). The authors discuss the major effects of manganese in O.H. steelmaking, considering deoxidation, hot workability, and mechanical and physical properties, including tensile strength, notch toughness, and hardenability.—G. F.

Oxidation of Phosphorus and Manganese during and after Flushing in the Basic Open Hearth. J. F. Elliott and F. W. Luerssen. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1954, **37**, 193–211). The authors discuss the factors influencing elimination of phosphorus and manganese during and just after the slag-flushing period in basic O.H. steelmaking. Data are presented indicating that distribution of the elements between slag and metal closely approach equilibrium during these periods. The apparent equilibrium temperatures appear much closer to the average slag temperature than to the bath temperature, a temperature difference up to 250° C. existing between the two phases. The effect of slag composition on the activity coefficient of MnO in the slag is estimated.—G. F.

The Effect of Alloying Elements on the Solubility of Nitrogen in Iron. Part I: The Solubility of Nitrogen in Pure Iron and in 2·83% Silicon Iron. N. S. Corney and E. T. Turkdogan. (*J. Iron Steel Inst.*, 1955, **180**, Aug., 344–348). [This issue].

The Viscosity of Liquid Iron and Iron–Carbon Alloys. R. N. Barfield and J. A. Kitchener. (*J. Iron Steel Inst.*, 1955, **180**, Aug., 324–329). [This issue].

Solubility of Nitrogen in Alpha-Iron. J. D. Fast and M. B. Verrijp. (*J. Iron Steel Inst.*, 1955, **180**, Aug., 337–343). [This issue].

The Solubility of Sulphur in Iron and Iron–Manganese Alloys. E. T. Turkdogan, S. Ignatowicz, and J. Pearson. (*J. Iron Steel Inst.*, 1955, **180**, Aug., 349–354). [This issue].

Behavior of Manganese in the Basic Open Hearth. D. W. Murphy and R. S. Miltenburger. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1954, **37**, 212–222). The authors have investigated 59 heats from four different melting shops, to study the behaviour of manganese during the various stages of the heat and the effects of temperature, slag composition, and metal condition. In flush-slag practice 75% of the manganese charged enters the flush slag. Throughout most of the finishing period carbon and manganese reactions with oxygen are apparently close to equilibrium.—G. F.

Pre-Refining Pig Iron in the Ladle. K. Heinrich. (*Hüttenwerk Oberhausen A.G., Technische Berichte*, 1951/54, Paper No. 5). In this process basic-Bessemer pig iron is pre-refined in the ladle by top-blowing with commercially pure oxygen. Between 50% and 60% of the silicon and manganese and all the vanadium are oxidized. The slag is used as an Mn-carrier for the blast-furnace, or as a source of ferrovanadium. Advantages of the process are: increase of the converter charge weight from 19 to 23 tons, reduced blowing time, and less nitrogen in the steel.—L. D. H.

Induction Stirring of Arc Furnace Charges. (*J. Four. Elect.*, 1953, **62**, Nov.-Dec., 165–168; 1954, **63**, Jan.-Feb., 13–17; Mar.-Apr., 48–62; May-June, 82–83). The use of induction stirring in the operation of arc furnaces manufacturing steel is described. The mode of stirring which occurs in normal operation and the changes which take place when induction stirring is used are considered. The electrical principles of the method are explained. The equipment used is described and results obtained are given. A short examination of the economics of induction stirring is presented which shows that the method is justifiable.—B. G. B.

Control of Emissions from the Electric Furnace. L. Krueger. (*Trans. Amer. Found. Soc.*, 1954, **62**, 496–498). The gradual

development of equipment designed to control the smoke and fumes emitted from an electric-arc furnace is described. In the system now used the dust is collected in a furnace hood, passed through a pre-cleaner where the air is washed by two sets of nozzles, through a fan and under a water spray to a water eliminator, and thence to the atmosphere.—B. C. W.

On the Microscopical Constitution of Basic Slags. Y. Shimokawa. (*Sumitomo Metals*, 1953, **5**, July, 135–148). [In Japanese]. Basic O.H. and electric-furnace slags were examined by thin-section methods and classified into three fundamental groups. Variations in constitution during the melting and refining periods were explored, and the practical relationship between the slag pancake and slag constitution was examined.

The Question of Citric Acid Solubility of Basic-Bessemer Slag on Refining with Oxygen-Enriched Blast. F. Kordon. (*Hüttenwerk Oberhausen A.G., Technische Berichte*, 1951/54, Paper No. 19). Investigation of the citric acid solubility of slags from basic Bessemer converters using oxygen-enriched blast showed that the use of oxygen in itself caused no reduction in solubility. Associated conditions such as low silicon in the pig iron and the use of refining ores containing fluorine were direct causes. The trouble can be prevented by raising the silica in the slag and using cooling and refining ores free from fluorine.—L. D. H.

Continuous Casting—Progress in America. J. S. Smart. (*Aust. Inst. Met. Conference; Australasian Eng.*, 1954, July 7, 57–71). The various processes now in operation for the continuous casting of aluminium, magnesium, copper, and other non-ferrous metals are described. A review of the difficulties and developments in the continuous casting of steel is then presented. The Babcock and Wilcox practice and the Hazelett process are both described, and possible future trends are indicated. (41 references).—P. M. C.

Application of the Process of Continuous Casting to Special Steels. M. J. Seloron. (*Doc. Mét.*, 1954, Apr.-May, 65–77). A review of continuous casting methods which are now in use is made and a description of the Jacob Holtzer plant in France is given. The output of the plant is only 1 ton/hr. but this is satisfactory as high-alloy steels are cast. Tool, stainless, and heat-resisting steels, and special high-alloy steels having magnetic properties are handled.—B. G. B.

Continuous Casting of Steel on an Industrial Scale. (*Aciers Fins Spéc. Franç.*, 1954, June, 60–63). A brief description is given of the development of continuous casting of steel at the Unieux works of the Compagnie des Ateliers et Forges de la Loire, where the first industrial plant was started up in 1953. The capacity of the plant is 25 tons/day, and it is intended to produce a wide range of special and alloy steels.

The Development of Continuous Casting and Direct Rolling of Steel. Z. Wusatowski. (*Hutnik*, 1954, **21**, (11), 370–375). [In Polish]. A survey of the literature of the Eastern and Western countries is given. (36 references).—V. G.

FOUNDRY PRACTICE

Practical Experience with the Graphite Bar Furnace. H. Reinfeld. (*Radex Rundschau*, 1954, (6), Aug., 175–193). The principles and construction of graphite bar furnaces are compared with those of other types of electric furnace. Applications for remelting and refining are discussed on the basis of experience gained during several hundred heats. Detailed data are given concerning performance and economics. The production of nodular cast iron is claimed as a further application.—E. C.

On Heredity of Pig-Iron. I. Effect of Gas-bubbling through Molten Iron. I. Iitaka and K. Nakamura. (*Waseda Univ., Rep. Castings Res. Lab.*, 1954, (5), 4–6). [In English]. Air, natural gas, Cl_2, O_2, and H_2 were bubbled through two types of iron, one being normally difficult to nodularize. H_2 and natural gas treatment produced marked increases in spheroidization. No definite reason can be attributed, although a small amount of desulphurization was observed.—K. E. J.

Effect of Oxides on the Structure of Gray Cast Iron. N. Kayama. (*Waseda Univ., Rep. Castings Res. Lab.*, 1954, (5), 14–18). [In English]. Studies were made on cast iron with controlled additions of $SiO_2 + FeO$, Al_2O_3, MgO, Cr_2O_3, ZrO_2, TiO_2, and CeO_2. The inclusions were found to impede the crystallization of graphite; the mechanism will clearly be of value in explaining defects in castings melted under oxidizing conditions, and will be investigated further.—K. E. J.

Considerations on High-Strength Gray Irons. A. De Sy. (*Rev. Soc. Roy. Belge Ing.*, 1954, June, 260–270]. The production of grey irons having a high resistance to wear and corrosion and a high capacity for damping vibrations is considered. Factors affecting the physical properties of grey irons are examined. The influence of graphite distribution and shape on the mechanical properties is discussed, with photomicrographs of grey iron structures.—B. G. B.

Dephosphorisation of Cast Iron by Adding Mg, Ca and Ce under Reducing Conditions. G. Östberg. (*Gjuteriet*, 1955, **45**, Feb., 24–25). [In Swedish]. Laboratory tests on a 2-kg. charge containing 0·93% P show that the phosphorus content can be reduced somewhat by the addition of Mg, Ca, and Ce. This method might be economic for the production of ferromanganese and ferrovanadium.—G. G. K.

Austenitic Spheroidal Graphite Cast Iron. Manufacture of Components for Aircraft and Welding Problems. (*Rev. Nickel*, 1954, **20**, Apr.-May-June, 31–36). The use of spheroidal cast iron for the main support ring in U.S.-produced Sapphire jet engines is described. The welding of 18/8 stainless-steel ribs joining two cast-iron parts is mentioned. Arc welding of the two materials is described in detail, giving properties of welded test pieces at various temperatures.—T. E. D.

On the Modulus of Elasticity E_0, of Foundry Irons Containing Nodular or Flake Graphite. W. Grundig. (*Bol. Assoc. Brasil Met.*, 1954, **10**, Apr., 111–140). [In Portuguese]. The significance of the modulus of elasticity, E_0, for graphitic materials is explained and compared with the value for steels. The influence of the amount, shape, and distribution of the graphite, the test-piece diameter, and the combined carbon content upon E_0 is discussed; the graphite content has the most important effect. The correlation of E_0 with the amount of graphite and the mechanical properties are given in the form of equations.—P. S.

Ferrous Materials Containing Nodular or Flake Graphite and Their Resemblance to Steel; Method of Assessment. W. Grundig. (*Bol. Assoc. Brasil Met.*, 1954, **10**, Apr., 141–154). [In Portuguese]. A standard method of assessment of ferritic materials containing graphite is required, and the author suggests that the modulus of elasticity, E_0, of such materials can be used as a criterion, since it varies directly with the graphite content and it can be compared with steels for which E is reasonably constant. The relationship $A = (E_0/E) \times 100$ is proposed and from it first-order equations are calculated for the variation of A with (*a*) graphite content, (*b*) the maximum-stress/hardness ratio, and (*c*) the bending-stress/hardness ratio.—P. S.

Spheroidal Cast Iron. Adding Method of Pure Magnesium Block and Magnesium Powder Briquette. T. Kusakawa. (*Waseda Univ., Rep. Castings Res. Lab.*, 1954, (5), 7–10). [In English]. Resin briquettes containing silicon, ferrosilicon, magnesia, or calcium carbide or silicide as well as magnesium will moderate the violent reaction with molten metal shown by pure magnesium. The pure metal may be introduced by a special plunger, but considerable skill is required.—K. E. J.

The Use of Statistical Methods for the Control of Production in a Malleable Iron Foundry. J. Piaskowski and J. Raczka. (*Przeglad Odlewnictwa*, 1954, **4**, (11), 317–327). [In Polish]. The use of statistical method for the control of production is discussed. Examples of this control applied to melting in cupolas and O.H. furnaces, preparation of moulding sands, heat-treatment, and properties of castings are given.—V. G.

Some Experiments on the Embrittlement of Malleable Iron. N. Tsutsumi. (*Waseda Univ., Rep. Castings Res. Lab.*, 1954, (5), 19–22). [In English]. Samples of iron with varying phosphorus contents, melted in the cupola or the Héroult furnace, were examined. Embrittlement may be attributed to intergranular precipitation or segregation of inclusions, possibly cementite, another carbide, iron phosphide, etc. It may be related to the transformation of Fe_3C to Fe_2C or $Fe_{20}C_9$.—K. E. J.

The Strength Measurement of Green Sand Molds. J. Kashima and A. Yaguchi. (*Waseda Univ., Rep. Castings Res. Lab.*, 1954, (5), 27–30). [In English]. Experiments were made on samples incorporating many kinds of binder. The green strength of the mould is the resultant of a dynamic and a static strength, and consequently results obtained for compression strength depend on the compression velocity, which may be controlled to give static strength alone. Other contributory factors, independent of the binder, are viscosity, surface tension, grain size, and ramming condition.—K. E. J.

Cast Iron Retorts for the Vacuum Distillation of Zinc. L. A. De Lacerda Santos. (*Bol. Assoc. Brasil Met.*, 1954, **10**, Apr.,

73–85). [In Portuguese]. The foundry technique for casting zinc distillation retorts in a heat-resisting cast iron (3·4% TC, 3·5% Si, 2% Cr, 0·8% Mn) is detailed. These retorts were made as a substitute for the expensive heat-resisting Cr–Ni steels and have proved successful, having a service life of about 600 hr. in the 830–870° C. range. Examination of the microstructure after considerable service shows that though the pearlite has spheroidized, the graphite flakes remain unaltered.—P. S.

Generalities on the Centrifugal Casting of Steel. (*Aciers Fins Spéc. Franç.*, 1954, June, 96–100). The three main methods of centrifugal casting are described, but only simple centrifugal casting is considered in further detail. The excellent characteristics of centrifugally cast steel tubes are discussed, with numerous examples of the use of such tubing. The possibility of obtaining tubes with composite walls by centrifugal casting is mentioned.—E. A. C.

Foundry Defects. A. Guacci. (*Fonderia Ital.*, 1954, **3**, July, 297–308). [In Italian]. Foundry objects can be classed into three groups: (i) important defects which result in the casting having to be scrapped; (ii) defects where repairs are so costly that it is doubtful whether they are economically justifiable; (iii) small defects which can be economically repaired. The faults occurring under these three categories are discussed in detail, their causes and the precautions to be taken to avoid them are examined.—M. D. J. B.

An Example of the Use of the Fluidity Test for Determining the Causes of Defects in Iron Castings. R. Krzeszewski and J. Marcinkowski. (*Przeglad Odlewnictwa*, 1954, **4**, (11), 313–317). [In Polish]. A statistical investigation of the dependence of the number of rejected castings on the fluidity of iron used indicated that the fluidity test can help in reducing the proportion of defective castings.—V. G.

HEAT-TREATMENT AND HEAT-TREATMENT FURNACES

Practical Application of Equilibrium Relationships to Heat Treating in Controlled Atmospheres. N. K. Koebel. (*Indust. Heating*, 1954, **21**, Dec., 2408–2418, 2577–2578). The author demonstrates that true equilibrium diagrams for gas–metal reactions are of little help to the practical heat-treater for the following reasons: (*a*) The accuracy of the equilibrium constant is doubtful; (*b*) true equilibrium conditions rarely exist in industrial furnaces; and (*c*) expensive equipment would be required to carry out accurate gas analyses. Instead, a method of control depending on measurement of dew-point for carburizing is proposed.—A. D. H.

Principles in the Heat Treatment of High Alloy Tool Steels. J. G. Ritchie. (*Aust. Inst. Met., Australasian Eng.*, 1954, Nov. 8, 52–61). This article covers the metallurgical principles involved in the heat-treatment of high-chromium and high-tungsten–molybdenum tool steels. The reactions involved in the hardening and tempering of the two classes of steel are reviewed with particular reference to the points of similarity and difference. The selection of a suitable treatment, and the variation in properties obtainable by changing the austenitizing temperature is emphasized. (30 references).

The Production of Heat-Treated SIGMA High-Tensile Steels. K. Ernst and S. Bonenberger. (*Tech. Mitt.*, 1953, (2), Dec., 85–90). The authors describe the plant and method for the production of high-tensile SIGMA steel wire (SIGMA is the name given by Hüttenwerk Rheinhausen AG. to their wire and rod for prestressed concrete). The heat-treatment plant consists of an electric annealing furnace 21 m. long through which 20 strands are pulled and heated to 850° C. This is followed by an oil quench, wiping, and tempering in a lead bath at 500° C. with final cooling by compressed air.—R. A. R.

Automatic Gas Carburizing of Automotive Gears. R. J. Peters. (*Indust. Heating*, 1954, **21**, Oct., 1938–1942, 1958). The process described uses an endothermic gas atmosphere to which hydrocarbons are added: C potential is controlled via the dew-point of the gas. The split manifold system of atmosphere introduction, saturation-diffusion method of carburizing, and quenching into oil at 150° F. are features of the system.—A. D. H.

Continuous Annealing of Stainless Steel Sheets in Roller Hearth Furnace. (*Indust. Heating*, 1954, **21**, Sept., 1718–1724, 1875–1878). The furnace operates continuously at 2100° F. and uses SiC rollers and radiant tubes. Sheet sizes handled are 24–62 in. wide and 72–144 in. long. Design details are given.—A. D. H.

Observations on the Annealing of Steel Strip. E. Nygren. (*Värm. Bergsmann. Ann.*, 1953, 108–137). [In Swedish]. Based on experience at the Munkfors mill, the author gives advice on the choice of a suitable time–temperature programme for annealing strip steel. After studying the permissible tolerances for strip hardness and structure in relation to the annealing process, he gives test data for annealing methods from which, in conjunction with the maximum permissible variations in hardness, it is possible to estimate the maximum time variation in the annealing temperature interval which is permissible between the hottest and coldest section of a batch of strip. Methods discussed include spheroidizing, annealing below and above the transformation point, and recrystallization annealing. Further sections deal with batch or continuous annealing, time required for absolute penetration of the heat into the innermost layer of the batch, and suitable types of annealing furnaces.—G. G. K.

Patenting Steel Wire Heated Directly by Electric Current. J. Lasota. (*Hutnik*, 1954, **21**, (11), 352–356). [In Polish]. The development of direct electric heating for steel wire and a laboratory installation for this purpose are described. The mechanical properties of steel wires patented in a furnace and by direct electric heating are compared.—V. G.

Study of the Influence of Tempering on the Microstructure and Mechanical Properties, in the Cold and Hot States, of Chromium–Molybdenum Steels. A. Constant and G. Delbart. (*Rev. Mét.*, 1954, **51**, Nov., 777–794). The results of a study of the influence of tempering on the flow-resistance of Cr–Mo steels are given. With a steel containing 2·25% Cr and 1% Mo, the effect of tempering is always unfavourable, except when carried out at low temperature for a short time, when a slight improvement in the resistance of the bainite structure is obtained.—G. E. D.

FORGING, STAMPING, DRAWING, AND PRESSING

Experiences with the Production of Large Forging Ingots Weighing up to 35 Tons. E. Johannson. (*Radex Rundschau*, 1954, (4–5), 107–121: *Iron Steel Inst. Translation Series*, 1955, *No.* 496). Experience in the production of 2000 ingots has been evaluated and the effect of various factors on ingot quality determined. The formation of ferritic boundaries (ghost lines) and their effect on ingot forgeability is dealt with. The sulphur content must be very low if special mechanical properties are required in the transverse direction. The effects of longitudinal cracks and oxide inclusions are investigated, and also temperature control, pouring and solidification rates, and mould maintenance.—G. G. K.

Why Stainless is Hard to Cold Head. W. M. Baldwin, Jun., and C. A. Beiser. (*Iron Age*, 1955, **175**, Jan. 13, 82–85). Stainless steel becomes brittle as the speed of cold-forming increases, hence cold-heading is difficult. Tests indicated that there is little improvement to be gained by varying the cold-heading technique.—D. L. C. P.

Hot Drawing of High-Nickel Alloys and of Steels. (*Rev. Nickel*, 1953, **19**, July-Aug.-Sept., 66–69). In the method discussed an oxide or salt, which in the molten state has a sufficiently high viscosity to enable it to form a lubricating layer, is interposed between the die and the metal being drawn. Some of the profiles produced are shown, and some applications are mentioned.—T. E. D.

Research on the Drawing of Mild Steel Tubes (I). T. Okamoto. (*Sumitomo Metals*, 1953, **5**, Apr., 61–84). [In Japanese]. With a deflection-type dynamometer, the drawing stress, plug stress, and drawing-force ratio were determined for sinking and plug-drawing conditions; the effects of plug shape, wall thickness, reduction, and die angle were considered. An approximation for the mean deformation resistance of annealed tubes is introduced.—K. E. J.

Wire Flattening—An Appraisal of Today's Theory and Practice. A. I. Nussbaum. (*Wire and Wire Prod.*, 1954, **29**, Aug., 857–859, 916–917, and Sept., 961–965, 1033). A formula for spread of wire during roll flattening is presented and illustrated by examples in which calculations are made with the help of charts. A simple theory of power requirements during rolling is given. This is followed by a description of the design and operation of wire-flattening mills, including such details as screwdown mechanism, roll materials, take-up reels, and automatic gauging.—J. G. W.

The Importance of Lime in Wire Drawing. T. C. Miller. (*Wire and Wire Prod.*, 1954, **29**, Aug., 843–850, 919). The role of lime in wire drawing is explained with a detailed discussion of the types of lime manufactured by different methods, in terms of their physical and chemical characteristics. Methods of testing calcium hydroxide suspensions are outlined, and results of investigations are quoted in which the specific surfaces of suspensions made from shaft and rotary kiln quicklimes were measured. The author concludes from these and other tests that rotary kiln pebble lime with particle size $\frac{1}{8}$–$\frac{3}{8}$ in. is most suitable.—J. G. W.

Wet Wire Drawing Lubricants. J. B. Bean. (*Wire and Wire Prod.*, 1955, **30**, Jan., 55–57). The following types of lubricant are described: straight soap, emulsion-type, and soap-fat, petroleum oil, and water-soluble oil. Lubricant concentration, maintenance, and testing are touched upon.

Dry Drawing Lubrication in the Wire Industry. L. Salz. (*Wire and Wire Prod.*, 1955, **30**, Jan., 51–55). Following a brief consideration of the factors influencing the performance of the lubricant, the author discusses the types of granulated soap, petroleum grease, and soap-fat paste compounds.

Wire Drawing Lubrication. G. Verner. (*Wire and Wire Prod.*, 1955, **30**, Jan., 47–50). The factors affecting lubrication in wire drawing are discussed under the headings metal of wire, surface condition, scale removal, mechanics of drawing operation, end use of wire. A simple list of the principal types of coating and lubricant is given.—J. G. W.

Continuous Patenting, Cleaning, and Coating. D. K. White. (*Wire and Wire Prod.*, 1954, **29**, Oct., 1131–1140, 1248–1251). Past and present methods of patenting, cleaning, and coating at the John A. Roebling's Sons Corp., Trenton, New Jersey, wire mills are described, and details are given of the new continuous plant. Production rates range from 1900 lb./hr. of 0·082 in. wire to 4000 lb./hr. of 0·148 in. wire. Constructional details of component units are illustrated and described.—J. G. W.

Cooling of Steel Wire During Continuous Drawing. N. A. Wilson. (*Wire and Wire Prod.*, 1954, **29**, Oct., 1160–1169, 1253). This is a detailed account of an investigation of the heating of wire in high-speed drawing and of the efficacy of air cooling, carried out on a Morgan-Connor, 7-block machine drawing air-patented, 0·70% C, 0·245-in. rod to 0·090 in. rope wire at 600, 900, and 1200 ft./min. It was found that the overall heat-transfer coefficient increased with air velocity up to a velocity of 9, and that in general the volume of cooling air should be increased with drawing speed. Nevertheless the wire temperatures are chiefly dependent on dies, lubrication, and wire properties.—J. G. W.

Prestressing Wires—Stress Relaxation and Stress Corrosion up to Date. G. T. Spare. (*Wire and Wire Prod.*, 1954, **29**, Dec., 1421–1424, 1492–1493). A free loop test of the susceptibility of high-tensile wires for prestressed concrete to stress-corrosion is described and results for different qualities of wire are quoted, together with relaxation and creep data. The test consists of looping wires round mandrels three times the wire diameter, allowing them to spring back, and exposing to corrosive media; damage is gauged by failure in unlooping. Results so far obtained suggest that oil-tempered wire is much more prone to stress corrosion than cold-drawn wire, principally owing to a high residual stress level. An increase in phosphorus content reduced the relaxation.—J. G. W.

Phosphate Coatings in the Cold Drawing of Steel Wire. J. F. Leland. (*Wire and Wire Prod.*, 1954, **29**, Dec., 1440–1443, 1479–1481). Phosphating and its impact on wire-drawing practice is reviewed on the basis of experience with the wet drawing of high-carbon wire at John A. Roebling's Sons Ltd. of Trenton, New Jersey, and with the dry drawing of stainless steel wire at Allegheny Ludlum Corp. of Dunkirk, New York. For best results included die angles between 10° and 14° are recommended. For wet drawing the first hole should be dry drawn with calcium stearate. Typical drawing schedules are quoted.—J. G. W.

The B.I.S.R.A. Profiloscope. A. E. Ranger. (*Wire Ind.*, 1954, **21**, Oct., 1015–1021). The principle of this instrument for the inspection of wire-drawing dies is explained and instructions for its use are given with the interpretation of images of carbide and diamond dies, as seen in the instrument. The three models of the Profiloscope cover the following size ranges: 0·40–0·04 in., 0·04–0·01 in., and 0·04–0·002 in. Reference is made to the British Standard specifications of profiles in diamond dies.—J. G. W.

Wire-Drawing Machines for Steel Wire: Methods and Equipment Used in Industry. H. Richards. (*Iron Coal Trades Rev.*, 1954, **169**, Dec. 17, 1447–1451). The author describes some of the latest equipment and methods used in the drawing of steel wire, and the economic aspects of the different methods are discussed.—G. F.

ROLLING-MILL PRACTICE

Calculation of Spreading and Forward Slip in Rolling. A. Geleji. (*Acta Techn.*, 1954, **9**, (3–4), 443–458). [In German]. The theory of spreading and forward slip is developed without the aid of empirical relations. The formulæ obtained are well substantiated by experimental tests.—P. F.

Roll-Bonding Process for Evaporator Plates. (*Engineer*, 1954, **198**, Dec. 24, 895–896). The article describes a new roll-bonding process developed by the Olin Mathieson Chemical Corp. of Illinois. The new process makes it possible to create any pattern of tubing, however intricate, within a single homogeneous sheet of metal.—M. D. J. B.

The Effects of Coiling Temperature on Hot Rolled Rod. R. A. Stebbins. (*Wire and Wire Prod.*, 1954, **29**, Oct., 1041–1042, 1247). Tests on the Sparrows Point rod mill and the rod and bar mill at the Johnstown plants of the Bethlehem Steel Company are quoted to show that the mill scale on wire rods increases with the rod coiling temperature, whence it is recommended to coil at about 870° C. in the interests of higher yield and lower acid consumption. The surface of the rod coiled at the lower temperature was smoother than that of hot-coiled rod.—J. G. W.

Mechanization of the Sheet Mill Train. A. Brüggemann. (*Hüttenwerk Oberhausen A.G., Technische Berichte*, 1951/54, Paper No. 7). The modernization and mechanization of the sheet-rolling plant at Oberhausen by which the monthly production has been increased from 2800 to about 4500 tons is described.—L. D. H.

Contribution to the Study of the Influence of the Method of Producing a Steel on the Suitability of Thin Sheets for Pressing. G. Husson, J. Stremsdoerfer, L. Beaujard, and J. Tordeux. (*Publ. Inst. Rech. Sid.*, Série **A**, 1954, (81), Oct., 143 pp.). Four steelworks participated in the trials, and each produced six casts by two different methods, which are fully described. Rolling procedure, and details of the pressing methods are then given. Mechanical testing is described, and the effect of production method on the results is discussed. Macro- and micrographic examinations were made, and distribution of inclusions is discussed. A critical note on the statistical interpretation of the results is appended. Results throughout are given in detail in tables, diagrams, and photographic plates.—T. E. D.

The Determination of Corrections for the Calculation of Elongation and Spread in the Hot Rolling of Alloy Steels. Z. Wusatowski and E. Szostak. (*Prace Instytutow Ministerstwa Hutnictwa*, 1954, **6**, (5), 217–220). [In Polish]. In order to adapt Wusatowski's formula for determining the elongation and spread of alloy steels during rolling, 13 types of steels (mainly Cr–Ni) were tested under normal rolling-mill conditions. On the basis of the results obtained the formula was modified by introducing a correction factor d, the values of which can be read off from the graphs given in the paper. With this modified formula other corrections for the effect of temperature, rolling speed, and the state of roll surface are unnecessary.—V. G.

Influence of the Temperature during the Final Pass on the Quality of Thin Steel Sheet. B. Otta. (*Hutník*, (Prague), 1954, **4**, (11), 328–332). [In Czech]. Results of cupping tests on thin sheet indicate that the final rolling temperature should be as high as possible, compatible with absence of sticking in the rolls and preservation of a good sheet surface. Measurement of the sheet temperature and the influence of the latter on rejects in deep-drawing are discussed.—P. F.

Cold Rolling of Serrionsat Strengthens Shaft, Lengthens Life. W. G. Patton. (*Iron Age*, 1954, **174**, Oct. 28, 92–93). Studies at the General Motors Corp. have shown that serrations formed by cold-rolling greatly improve the service life of steering gear wormshafts by increasing their resistance to tension, shear, and fatigue loading. The process is used on tubular and solid steel shafts, and gives greater accuracy at lower cost than hobbing.—D. L. C. P.

New Developments in the Manufacture of Transformers and Our Approach Thereto. O. Twerdy. (*Met. u. Giesserei Techn.*, 1954, **4**, Oct., 426–427). An historical survey of the develop-

ment of transformers is followed by a description of the cold-rolling of transformer sheet by American methods now being employed in Eastern Germany. Sheets 30 in. long and 8 mm. thick are reduced to 0·35 mm. thick.—L. J. L.

The Production of Cold-Rolled Electrical Steel Sheet with Low Watt Losses. W. Kunze. (*Met. u. Giesserei Techn.*, 1954, **4**, Oct., 431–434). Strips of silicon steel (C, 0·04%; Si, 3·32%; Cu, 0·28%) were given different degrees of cold reduction and annealed at different temperatures to determine the conditions leading to minimum watt losses. A reduction of 65% and annealing at 850° C. gave the best results.—R. A. R.

Inauguration of the Mannesmann Works at Belo Horizonte. (*Eng. Min. e Met.*, 1954, **20**, Sept., 120, 160). [In Portuguese]. The speech of inauguration of the Mannesmann Company's seamless-tube plant at Belo Horizonte, Barreiro, Brazil, is reported. In 1956 a production of 100,000 tons of steel tubing ($\frac{3}{8}$–8$\frac{5}{8}$ in. dia.) is expected.—P. S.

Photo-Electric Controls in a Rolling Mill. T. W. Brady. (*Engineering*, 1954, **178**, Dec. 17, 788–789). This article describes equipment installed in the premises of Scunthorpe Rod Mill Ltd., Scunthorpe, which consists of two photo-electric cells situated between stands 5 and 6 of a rod mill. The cells ensure that twist and shear are applied at the correct instant.—M. D. J. B.

MACHINERY FOR IRON AND STEEL PLANT

The Dilution Method for Industrial Waste Disposal. H. S. Kline and J. F. Fletcher. (*General Motors Eng. J.*, 1954, **1**, Sept.-Oct., 38–43). The authors describe a system for the river disposal of industrial acid and alkaline waste whereby the discharging, combining, and dilution of plant wastes are regulated and controlled by sampling.—J. E. J.

Recent Developments in Aids to Labor. H. A. Parker. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1954, **37**, 86–87). The extent to which operations have been mechanized in the open hearth shop at Fairless Works, United States Steel Corp., is outlined. The main developments are in handling of ferromanganese, auxiliary crane services, and mechanical aids in rebuilding.—G. F.

Recent Developments in Aids to Labor. V. W. Jones. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1954, **37**, 87–90). Brief details and illustrations are given of recent aids to handling and lifting operations in O.H. shops.—G. F.

Recent Developments in Aids to Labor. G. E. Cooper. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1954, **37**, 78–85). Recent developments at the Steel Co. of Canada Ltd. include improved handling of ferro-alloys and raw materials from the stockyards to the shop floor, mechanical removal of debris during rebuilding, improved auxiliary crane service, and semi-automatic mould strippers.—G. F.

Water in Iron and Steel Works. M. Steppes and P. Mosel. (*Rev. Tech. Luxembourg*, 1954, **46**, July-Sept., 138–163). A comprehensive review of the design of the distribution of water in steelworks is presented. Examples of actual water-distribution schemes are given and examined. The consumption of water in blast-furnaces, melting shops, and rolling mills are shown. Methods used for the chemical treatment of water on a large scale are reviewed and examples of calculations of the amount of chemical required for this purpose are given.—B. G. B.

Some Comments on Waste-Heat Boiler Practice. W. Gregson. (*J. Iron Steel Inst.*, 1955, **180**, Aug., 369–377). [This issue].

Two Gas-Turbine Installations in Steelworks. G. Waller. (*Oil Eng. and Gas Turb.*, 1954, **22**, Aug., 152–153). The author discusses the performance of two Brown-Boveri gas-turbines, one installed in the Dudelange Steelworks, Luxembourg, and the other in the Baracaldo (Spain) Steelworks. The Dudelange plant is rated at 5,400 kW.; it is a single-shaft recuperative machine. The Spanish installation, a dual-fuel type, has a 15-stage compressor driven by a 6-stage turbine.—L. E. W.

Iron-Ore Transporters at Bidston Dock. (*Engineering*, 1954, **178**, Dec. 17, 796–800). This article describes the two 350-ton/hr. transporters installed at Bidston Dock, Birkenhead, primarily for handling iron ore for the steelworks of John Summers and Sons, Ltd., Shotton.—M. D. J. B.

The Application of Conveyors to the Handling of Materials in Bulk. J. Findlay. (*Trans. Inst. Eng. Ship. Scotland*, 1953–54, **97**, 153–203). The handling of materials by belt, chain, and screw conveyors, bucket elevators, and skip hoists is described.—J. E. J.

Highly Developed Conveyor System Combines Versatility with Maximum Handling Efficiency. E. C. Beaudet. (*Iron Age*, 1954, **174**, Oct. 7, 126–129). The handling system in the cold-extrusion plant of the Heintz Mfg. Co., Philadelphia, is described and illustrated.—D. L. C. P.

Coke Conveyor Installed at the Newcastle Steel Works. (*B.H.P. Rev.*, 1954, **31**, Sept., 14–16). A description is given of the installation of a conveyor belt about 600 yd. long and 60 in. wide, for the transport of coke from the coke ovens to the blast-furnaces at Newcastle, N.S.W.—L. D. H.

Kembla Works Coal Haulage System Modernised. (*B.H.P. Rev.*, 1954, **31**, June, 14–16). Details are given of the problems overcome in the construction of a new rail system for coal haulage to the Kembla Works of the Australian Iron and Steel Co.—L. D. H.

WELDING AND FLAME-CUTTING

Fundamental Researches on Austenitic Welding of Various Plain Carbon and Alloy Steels. M. Okada and H. Ikawa. (*Tech. Rep. Osaka University*, 1954, **4**, Mar., 137–162). In the case of plain carbon steels penetration variables tended to increase with welding current, with carbon content of base metal. D.C. yielded a higher penetration rate than A.C., but reversing the polarity did not affect it materially.—J. G. W.

Faults in Welds: Causes and Cures. W. S. Coates. (*Australasian Eng.*, 1954, Oct. 7, 83–84). A brief review is presented of the development of the coated consumable electrode. Weld porosity, cracks, and slag inclusions are discussed, and reference is made to physical, X-ray, and magnetic test methods.—P. M. C.

Modern Oven Installation for Producing Coated Welded Electrodes. (*Indust. Heating*, 1954, **21**, Oct., 2050–2058–2070).

A Method of Welding Joints In Austenitic Manganese Rails. C. Hanappe. (*Rev. Soudure*, 1954, **10**, (3), 133–135). The method described consists in welding the two rail ends to a vertical plate inserted in the rail joint. Details of welding procedure and electrodes are given. Results of fatigue tests on the welded joints are also given.—M. D. J. B.

Study of the Weldability of 37 H.S. Steels. J. Massinon. (*Rev. Soudure*, 1954, **10**, (4), 216–228). This paper describes a series of tests carried out on a number of steels produced under controlled conditions to ascertain their welding characteristics. The results of detailed experiments are given.

A Contribution to the Problem of Non-Metallic Inclusions In [Weld] Deposited Metals. J. M. Sistiaga and W. Koch. (*Cien. Tecn. Solda.*, 1954, **4**, Nov.-Dec., 1–7). [In Spanish]. A chemical and morphological examination of non-metallic inclusions, electrolytically extracted from arc-weld deposited mild steel, is described. Four different coatings were studied and have shown that (*a*) the mineral acid or rutile type of coating develops the greatest oxide content in the metal and basic coatings the least; and (*b*) slag-metal equilibrium is not obtained in the weld. It is suggested that the lamellar form of inclusions produced by silica-rich slags might be responsible for hot-cracking.—P. S.

The Problem of Arc Weld Cracking in Alloy Steels. F. Donis Ortiz. (*Cien. Tecn. Solda.*, 1954, **4**, Sept.-Oct.; Nov.-Dec.). [In Spanish]. An extensive review of the subject is supplied. The welding of heat-resisting and stainless steels, and welding in modern gas turbine construction are discussed and illustrated. Tables of typical compositions and uses of the various steels are given. The metallography of chromium, nickel, and manganese steels and the variables which influence the problem of weld cracking and the choice of electrode and technique for a variety of steels are discussed. The use of good quality electrodes in conjunction with good preparation of the joints, pre-heating, and heat-treatment enables many of the weld-cracking problems to be solved.—P. S.

New Approach to the Theory of Residual Stresses in Welds. F. K. G. Odqvist. (*I.V.A.*, 1954, **25**, (6), 259–263). [In English]. A theory presented for calculating residual stresses in fusion welds takes into account plastic yield of the slip type together with viscous creep. The case of two weld-jointed rectangular plates is studied, a differential equation being established which permits stress calculation.—G. G. K.

Low-Temperature Stress Relieving—Principles and Practices. T. W. Greene. (*Proc. International Acetylene Assoc.*, 1948, 1949, and 1950, 147–158). An analysis is given of the residual stresses in and immediately adjacent to welded joints. Mechanical and controlled low-temperature methods of stress relief are discussed, and a method of stress determination is

described. The application of the method to tankers, pressure vessels, large tanks, and thick plate is described.—J. E. J.

Oxy-Acetylene Flame-Conditioning. N. H. Cuke. (*Proc. International Acetylene Assoc.*, 1948, 1949, and 1950, 131–144). The conditioning of scaled billets, forgings, and castings, of scaled and rusted steel prior to painting, and of painted steel before repainting is discussed. The equipment and gas supply, various oxy-gas flames, and costs and applications are discussed. Some new uses for the flame-conditioning torch include rubber removal from rubber-lined steel tanks, the removal of weather-proof coating from concrete, stucco, and masonry, and the removal of tar-base and asphalt-base paints from steel.—J. E. J.

Flame-Hardening—Principles, Applications, and Equipment. M. S. Rosengren. (*Proc. International Acetylene Assoc.*, 1948, 1949, and 1950, 116–121). The general principles of flame-hardening are discussed and a description is given of the stationary, spinning, progressive, and combination methods.

Oxy-Acetylene Cutting—Scope, Methods, and Equipment. R. F. Helmkamp. (*Proc. International Acetylene Assoc.*, 1948, 1949, and 1950, 106–111). The oxy-acetylene cutting torch is compared with other steel-cutting equipment, and a general description of oxy-acetylene cutting equipment is given. The scope of the applications of oxy-acetylene cutting is outlined.

Practical Safety Considerations in Oxy-Acetylene Applications. J. I. Banash. (*Proc. International Acetylene Assoc.*, 1948, 1949, and 1950, 95–105). The safety precautions which should be practised in the oxy-acetylene industry are outlined. These include pressure precautions with regard to cylinders, the distribution of pipe lines, and pressure regulators, precautions against the reactivity of oxygen with grease and against the decomposition of acetylene, and precautions against the flame. Protective clothing and fire prevention are also discussed.—J. E. J.

MACHINING AND MACHINABILITY

Inexpensive Method of Measuring Surface Finish. M. Matsunaga and S. Yamasaki. (*Rev. Sci. Instruments*, 1954, **25**, Dec., 1221–1222). The electrical surface contact resistance of a number of steel and non-ferrous surfaces was measured, using a graphite sliding contact and low voltage to prevent breakdown of the oxide films. Results obtained were compared with the diffraction patterns formed, and it was found that electrical resistance could be correlated with surface finish.—L. D. H.

Surface Damage in Grinding of Steel. R. L. Kamm. (*Aust. Inst. Met.; Australasian Eng.*, 1954, Nov. 8, 62–70). Various types of surface injury are described, including cracks, residual stresses, and metallurgical ' burn ' in the case of hard steels, and work hardening, residual stresses, and quench hardening in the case of soft steels. Methods of reducing surface damage are discussed including control of metallurgical variables, grinding variables, and, in particular, lubrication.

Electrolytic Grinding. G. Comstock. (*Aircraft Prod.*, 1954, **16**, Dec., 488–490). Electrolytic grinding, as developed by the Norton Company, Worcester, Mass., is described, and a typical graph of stock-removal rate *v.* electrolysing current-density is shown.—T. E. D.

Machinability and Microstructure of Cast Irons. E. A. Loria. (*Trans. Amer. Found. Soc.*, 1954, **62**, 163–175). Results are presented to show the correlation between the microstructure and machinability of grey cast iron. It was found that machinability improved as the graphite–pearlite distribution became coarser but was decreased drastically by about 5% free carbide. In alloy cast irons, nickel had a beneficial effect on tool life, but additions of chromium and molybdenum decreased it by stabilizing the carbide. The machinability of high-phosphorus iron was found to compare favourably with that of low-phosphorus iron, and 5% steadite in the structure had no adverse effect.—B. C. W.

Grinding Cemented Carbides. A. H. Allen. (*Metal Progress*, 1954, **66**, Dec., 115–119). New grinding techniques (electro-discharge, electrolytic, ultrasonic, silicon carbide belt, and wheel grinding) have reduced the need for diamond wheels in tool dressing. Improvements in diamond grinding and efficient salvage of waste materials help to conserve the dwindling supply of bort.—B. G. B.

Some Recent Advances in the Interferometric Study of Surface Shape. B. Edenholm and E. Inglstam. (*I.V.A.*, 1954, **25**, (5), 194–203). [In English]. Details are given of recent types of interferometers and their capabilities, with special reference to multiple-beam interferometry and immersion interferences.—G. G. K.

Application of the Two-Beam Interference Microscope to the Study of Surfaces. W. L. Grube and S. R. Rouze. (*J. Opt. Soc. Amer.*, 1954, **44**, Nov., 851–860). Present instruments are capable of examining surface detail in the range of 2–100 microinches peak-to-valley. Applications to the study of surfaces important in industry are discussed.—E. C. S.

Investigations on Surface Finish of Steel Shafts. A. S. T. Thomson, A. W. Scott, W. Ferguson, and G. V. Stabler. (*Trans. Inst. Eng. Ship. Scotland*, 1953–54, **97**, 549–586). The authors discuss the wear and performance of scraping tools with regard to tool material, cutting speed, and surface finish. The results of a series of tests to determine the quality of finish produced on mild steel by a variety of methods are given; these methods include emery polishing, superfinishing, honing, wet scraping, grinding, and combinations of these methods.—J. E. J.

CLEANING AND PICKLING

On the Descaling and Chemical Polishing with Hydrogen Peroxide Solution (I). K. Kawamura. (*Sumitomo Metals*, 1953, **5**, July, 154–166). [In Japanese]. H_2O_2 mixed with inorganic or organic acids can be a better solvent for scale than ordinary acid solutions, and may be used for pickling various alloy steels and alloys of nickel and cobalt, previously thought difficult to descale. The metal base is hardly affected.—K. E. J.

Preparing Metal Surfaces by Oxy-Acetylene Burner. E. Sellier and C. Robeyns. (*Ossature Métallique*, 1954, **19**, Dec., 599–602). The authors describe a method of cleaning metal surfaces by using an oxy-acetylene flame with temperatures up to 3100°C. At these temperatures all combustible materials such as greases, oils, scale, paints, etc., are burnt and dampness is vaporized, leaving the metal surface ready for painting immediately after brushing down.—M. D. J. B.

Metal Descaling by the Sodium Hydride Process. (*Corrosion Prevention and Control*, 1954, **1**, Nov., 539–541, 575). The advantages of descaling metal by the sodium hydride process (now practised at the Staines works of Durtnall and Hipwell, Ltd.) are enumerated. Most metals can be descaled effectively by this method. The steps involved are outlined and a brief description of the plant is given and economic aspects are considered.—L. E. W.

Descaling Steel with the Aid of Oxidizing Pastes. J. Frasch. (*Métaux–Corrosion–Indust.*, 1954, **29**, Nov., 438–445). The method described is based on the controlled formation of a thin film of rust between the steel and the scale which can then be easily removed by mechanical means. It is shown that the mechanism of this formation of rust is electro-chemical. The reactions occurring at the steel/scale interfaces and the action of the oxidizing pastes, which are used to remove scale are explained.—B. G. B.

Cleaning of Stainless Steel for Wire Drawing. J. H. Corson. (*Wire and Wire Prod.*, 1954, **29**, Oct., 1143–1147). The factors underlying the make-up of oxidized surfaces of stainless steels are reviewed and various cleaning practices used in the stainless-steel wire industry are discussed. Chemical compositions and structures of oxide films are quoted.—J. G. W.

Alkali Replaces Acid in Plating Lines. (*Steel*, 1954, Oct. 4, 104–105). The ' Alka-Deox 134 ' process of Enthone Inc. is described. It is an alkaline derusting process, and its incorporation into a brass or cadmium plating machine is described.

PROTECTIVE COATINGS

Electron Diffraction Studies on Oxide Films formed on Metals and Alloys. G. Honjo. (*J. Phys. Soc. Japan*, 1953, **8**, Jan.-Feb., 113–118). Surface oxidation products of various alloys, including 13% Al–Fe, were studied within range 300–900° C. and 10^{-4}–760 mm. Hg. At low pressure and high temperatures the baser component was oxidized selectively. Aluminium trioxide was prevalent in the Al–Fe alloy at lower pressures, and ferrous–ferric oxide and α-ferric oxide at higher pressures, but the products were generally more complex than in other alloys owing to the selective oxidation of aluminium and the protective nature of the film produced.

Ion Exchange A Practical Tool in the Plating Room. R. J. Keating. (*Metal Finishing*, 1954, **52**, Dec., 52–55). The use of ion-exchange materials for water softening, purifying

plating baths, for treatment of effluents for recovery of valuable metal and the treatment of waste liquors is described with examples.—A. D. H.

On the Structure of the Oxidation Interface of Iron. R. Sifferlen and R. Collongues. (*Compt. Rend.*, 1954, **238**, May 31, 2167–2169). Samples of pure iron prepared in the laboratory and of industrially pure iron were oxidized under identical conditions. The oxidation interface was studied under the microscope. In the first case the interface was linear, and in the second irregular due to segregation and to internal oxidation of elements more easily oxidized than iron. A thin band of finely crystallized material was also observed at the interface, different in composition and structure from the adjacent iron.—G. E. D.

Protecting the Health of Operators in Chromium, Nickel, and Cadmium Plating Shops. L. Lepage. (*Pact*, 1954, Dec., 444–452).

Experiments on the Application of Inductive Heating to the Sintering and Alloying of High Melting-Point Metals and to the Heat-Treatment of Sprayed Metal Coatings with the Base Substance. K. Krekeler. (*Forschungsberichte des Wirtschafts- und Verkehrministeriums Nordrhein-Westfalen. No.* 47, 1953). Experiments carried out with inductive heating showed that pulverized iron and nickel carbonyls could be sintered very rapidly; in the case of iron carbonyl, pre-pressed at 5 tons/sq. cm., sintering at 1450° C. was complete in 18 sec., the density of the sintered product being 7·2 g./c.c. against 6·3 g./c.c. in the unsintered condition. A sintered alloy of 75% Fe and 25% Ni-carbonyl gave a hardness value of $HV = 345$ kg./sq. mm. Experiments carried out on iron sheet metallized with iron and with chromium–nickel wires, and inductively heated at 1350° C., showed, in the case of the latter, a layer diffused into the base metal, and complete freedom from slag and porosity.—L. D. H.

The Effect of Organic Inhibitors on the Solution of Iron in Acids. J. Elze. (*Metalloberfläche*, 1954, **8**, Dec., A177–A179). It is pointed out, in investigating whether an organic inhibitor influences the cathodic or anodic solution of iron in acids, allowance should be made for the possibility of the reduction of the inhibitor. If the local hydrogen electrode is exchanged for a Redox electrode, which is insensitive to the inhibitor, the effect of the inhibitor on the anodic solution can be studied. The inhibitor chinoline is discussed in detail.—L. D. H.

Measurement of Plating Thickness. G. Howells. (*Corrosion Techn.*, 1954, **1**, Sept., 233–236). The author discusses methods of measuring plating thickness, dealing firstly with chemical methods such as the B.N.F. jet test and the Francis thickness test. Magnetic methods are described with particular reference to the instrument developed by Tait. The use of X-rays, and of eddy currents to measure insulating coatings are dealt with.—L. E. W.

Measurement and Control of the Thickness of Thin Films. K. M. Greenland. (*Vacuum*, 1952, **2**, July, 216–230). The principles and some refinements of the gravimetric, photometric, polarimetric, and interferometric methods of measuring thin film thicknesses are described together with examples of X-ray, radioactive tracer, and electrical methods. (56 references).—L. E. W.

Galvanizing and Painting. W. Brachmann. (*Metalloberfläche*, 1954, **8**, Oct., A157–A16170; Nov., A2–A176). The protective action of zinc coatings against corrosion is discussed. The advantages of a combination of galvanizing and painting is outlined, and the coating technique summarized. Reference is made to the development and application of zinc dust colouring. In the second part the techniques for obtaining adhesion between the paint coating and the galvanized surface are discussed.—L. D. H.

Tin–Zinc Alloy Plating. (*Corrosion Prevention and Control*, 1954, **1**, Dec., 601–605, 622). The composition, corrosion resistance properties, limitations, and typical applications of tin–zinc plating alloys are considered and the plating process is outlined. Some performance data obtained by the Tin Research Institute for tin–zinc, zinc, and cadmium coatings exposed to various corrosion environments are compared.

Tin–Zinc Plating. (*Aircraft Prod.*, 1954, **16**, Dec., 497–498). Details of the process are given. Maximum protection is obtained with 25% Zn. A thickness of 0·0005 in. is sufficient for most purposes. Plating equipment, preparation of electrolyte, preparation of work, and passivation of the coatings are described.—T. E. D.

High Speed Brass Plating. T. Z. Voyda. (*Metal Finishing*, 1954, **52**, Dec., 56–60). The characteristics of brass plating baths containing potassium salts enabling deposits 0·001 in. in thickness using current densities of 20–30 A./sq. ft. are described in detail.—A. D. H.

Chemical Surface Treatments Applied to High Nickel and Chromium Stainless Steels and Alloys. J. Bary. (*Rev. Nickel*, 1954, **20**, Apr.-May-June, 27–29). The advantages of surface treatment of high nickel and chromium alloys during cold-working are discussed. Particular reference is made to the 'Bonderite SS' process in which the metal is thoroughly cleaned by a series of acid treatments, followed by immersion in an oxalate bath. This process has been used in improving the performance of welds joining reels of wire in continuous wire-drawing, and it has also made possible an increased reduction in the drawing of 18/8 stainless-steel boiler tubes without intermediate reheating.—T. E. D.

Experimental Study of the Adhesion of Enamel to Metal. S. J. Tonachella. (*Métaux–Corrosion–Indust.*, 1954, **29**, Nov., 415–430; Dec., 483–509). The properties and methods of production of enamel coats on metals for use at room temperatures are first described. Types of enamel coatings suitable for use at elevated temperatures are then reviewed. Work carried out on the nature of the metal–enamel bond and on the mechanical strength of coatings is considered. The methods used to study the adhesion of coatings is reviewed and details and results of a new testing method are given.

Ceramic Coatings for Alloys. (*Corrosion Prevention and Control*, 1954, **1**, Dec., 614–616, 626). Details are given of the composition and qualities of ceramic coatings developed by the U.S. National Bureau of Standards for high-temperature alloys, particularly for those used in the exhaust systems of aircraft where they are exposed to lead bromide vapours. The most successful and widely used of these ceramic coatings is A–417 composed of high barium, alkali-free frit with a 30% admixture of chromic oxide. The coating is applied in the form of a water suspension and then fired. So far A–417 has been used mainly with Inconel and 19–9 DL, HS–21, S–816, and 18–8.—L. E. W.

Adherence of Porcelain Enamel to Steel. (*Ceramics*, 1954, **6**, Aug., 262–268). Investigations carried out for the U.S. National Bureau of Standards, on the mechanism of the adherence of porcelain enamel to enamelling iron, are described and the conclusions given. The roughness of the interface formed during the firing process was found to be important, but other factors are involved.—D. L. C. P.

Passivation by Means of Coats of Paint. H. Hebberling. (*Metalloberfläche*, 1954, **8**, Dec., A188–A189). The use of 'reaction primers' in providing a passivated undercoat in the painting of metal surfaces is described.—L. D. H.

PROPERTIES AND TESTS

Yield Behaviour of Metals at High Temperatures with Particular Reference to Some Carbon and Low-Alloy Steels. H. F. Hall and R. W. Nichols. (*J. Iron Steel Inst.*, 1955, **180**, Aug., 324–329). [This issue].

Comparison of the Hardening Produced in a Yield Point Steel by Uniaxial Loading Under Static and Under Dynamic Conditions. D. B. Harris and M. P. White. (*J. Appl. Mech.*, 1954, **21**, June, 194–195). Experiment has shown that an annealed low-carbon steel wire had a higher microhardness when subjected to repeated uniaxial tensile impact than when stretched statically or when in the unstrained condition.—D. H.

Portable Diamond Indenter Hardness Testers. (*Engineer*, 1955, **198**, Dec. 24, 881). Two new instruments by Vickers Ltd. are described.—R. A. R.

Atomistic Concepts on Plastic Deformation and Recrystallization of Metals. A. Schäfer. (*Arch. Eisenhüttenwesen*, 1954, **25**, Nov.-Dec., 621–627). The work-hardening observed in metallic solid solutions is attributed to a subdivision of the grains in domains. Superposition of the time-dependent forces leads to work-hardening in combination with the shift in phase caused by the deformation of the material. The domains are separated by slip bands and by lattice distortion in the immediate vicinity of the slip bands. Similar considerations can be applied to hardening and age-hardening.—T. G.

Effect of Cold Work and Ageing on the Strength and Ductility of Low-Carbon Special Steels Blown in the Converter. A. Krüger. (*Stahl u. Eisen*, 1954, **74**, Dec. 30, 1757–1766). The quality of basic-Bessemer steels was improved considerably in recent years by blowing with oxygen-enriched air, or steam, oxygen and CO_2, or a mixture of these. Rimming and

killed steels from the basic converter blown with oxygen-enriched air and a mixture of air, oxygen and steam were compared with ordinary basic-Bessemer, O.H. and electric furnace steels with respect to composition and mechanical strength before and after cold working. The nitrogen and phosphorus contents were approximately the same in all the steels but the oxygen content differed considerably. Tensile strength, necking, elongation, and notch-impact data increased less after cold working than those of ordinary basic-Bessemer steel. Ageing was also studied and the dominating influence of nitrogen and phosphorus was established. With high nitrogen plus phosphorus there was a marked increase in tensile strength after cold work. The effect of phosphorus alone appears to be stronger than that of nitrogen alone. Steels blown with steam plus oxygen added to the blast were superior and very similar in all respects to O.H. steels.

The Use of Zephiran Chloride as Etchant in the Investigation of Temper Brittleness, Age Brittleness, and Stress Corrosion of Steels. H. K. Görlich, E. Koerfer, G. Obelode, and H. Schenck. (*Arch. Eisenhüttenwesen*, 1954, **25**, Nov.-Dec., 613–619). Directions are given for the etching of steel with Zephiran chloride (alkyldimethylbenzylammoniumchloride) including precautions to be observed for obtaining proper results. A comparison of Zephiran chloride etchings of a basic-Bessemer steel with autoradiographs, using radioactive carbon, leads to the conclusion that the carbon compounds are preferentially attacked by the former.—T. G.

A Discussion of Some Recent Theories on the Cause of Temper Brittleness in Steel. A. M. Sage. (*Metal Treatment and Drop Forg.*, 1954, **21**, Oct., 463–468). An assessment of the present state of knowledge concerning the cause of temper brittleness is made. Recent research indicates that the condition can be attributed to grain boundary segregation of certain elements. Characteristics of elements giving rise to temper brittleness are discussed and a tentative explanation is given for the behaviour of molybdenum, which causes temper brittleness in the absence of other alloying elements, but reduces the susceptibility in steels containing manganese or chromium. (16 references).—P. M. C.

Effect of the Ratio of Rubbing Surface to Hardness on Slipping Conditions of Machine Parts in Contact. D. N. Garkunov and I. V. Kragelsky. (*Doklady Akademii Nauk S.S.S.R.*, 1953, **91**, 1085–1088: *Nat. Sci. Foundation Translation No.* 178, Jan., 1954).

Some Ideas on the Concept of Quality. E. Houdremont. (*Berg u. hüttenm. Monatsh.*, 1953, **98**, Dec., 247–256). This lecture is a wide philosophical survey of the concept of steel quality and related phenomena. The crystalline nature and atomic structure of iron are considered. Properties, structures, and defects of various types of iron and steel are outlined, and special attention is given to magnetic properties.—E. C.

The Concept of Resilience. (*Aciers Fins Spéc. Franç.*, 1954, June, 76–81). A short outline of the nature of the brittleness of metals is followed by a definition of resilience (notch toughness). Reference is made to the Charpy impact test, together with a discussion on the influence on results of the major variables, i.e. impact speed, notch characteristics, and temperature. A description is given of the probable stress distribution in the specimen during testing.—E. A. C.

On the Mechanism of Annealing Treatment for Stress Relief. M. Watanabe and K. Satoh. (*Tech. Rep. Osaka University*, 1954, **4**, Mar., 71–81). Mechanism of stress-relieving treatment was studied from point of view of welding stress and creep and relaxation phenomena of structural steel. A theory of stress relief by annealing was developed on the basis of tensile creep measurements and compared with experimental findings.—J. G. W.

The Resistance to Creep of Steels Used in Power Stations. G. Delbart. (*Bulletin SFM No.* 10, 1954, 3–15). After explaining the importance of creep-resistant steels, a description of methods used to measure creep resistance is given. The creep-resistance of the steels used in the construction of power stations are reported and the influence of each alloying element on the properties is explained. The importance of the heat-treatment of a steel on its creep resistance is stressed and an example is given of the influence of heat-treatment on a 0·6%-Cr 0·6%-Mo steel.—B. G. B.

Improving the Resistance of Strain Gauges to Alternating Stresses. G. Vidal, J. Laxague, and P. Lanusse. (*Recherche Aeronaut.*, 1954, Mar.-Apr., 53–56). Under certain conditions of alternating stress the usual type of resistance wire strain gauge is liable to fracture. The authors describe a simple modification to their design which has overcome this defect. The results of fatigue tests carried out on these strain gauges are given.—B. G. B.

The Fatigue of Carbon Steel (Report III). H. Yamanouchi and T. Inukai. (*Waseda Univ., Rep. Castings Res. Lab.*, 1954, (5), 42–43). [In English]. Work on steels containing 0·30%, 0·68%, and 0·79% C shows that etching techniques and ultrasonic attenuation may be used to explore the fatigue behaviour.—K. E. J.

Development and Position of Soft Magnetic Materials. H. Fahlenbrach and W. Heister. (*Techn. Mitt. Krupp*, 1954, **12**, Jan., 27–35). The development, magnetic and physical properties of alloys used for non-permanent magnets (with the exception of steels for dynamos and transformers) is discussed.—L. D. H.

Effects of Aluminium in Fe–Ni–Al System, and of Aluminium, Cobalt and Nickel in Fe–Al–Ni–Co System. M. Chubachi. (*Sumitomo Metals*, 1952, **4**, Oct., 429–439; 1953, **5**, Jan., 22–37). [In Japanese]. For both systems, the critical cooling velocity is the most important factor determining the magnetic properties. In the Fe–Ni–Al system it is largely governed by Al content, the optimum being 12–17%. In the Fe–Ni–Al–Co system it is inversely proportional to Ni content but exhibits maximum values with variations in either Al or Co content.—K. E. J.

Iron–Nickel Alloys with a High Magnetic Permeability. E. Josso. (*Rev. Nickel*, 1954, **20**, July-Aug.-Sept., 53–64). Magnetic iron–nickel alloys, their classification, and the physical and chemical effects of heat-treatment, are described. The characteristics of ferro-nickels with orientated crystals are discussed, and the properties of a new alloy, Rectimphy, are described. The properties of Permafix, an orientated ferro-nickel with a constant permeability, are also given.

The Enthalpy and Specific Heat of Iron and Steel. A Critical Survey of the Methods of Determination. J. R. Pattison. (*J. Iron Steel Inst.*, 1955, **180**, Aug., 359–368). [This issue].

Improvements in Ultrasonic Flaw Detection. G. Bradfield. (*J. Brit. Inst. Radio Eng.*, 1954, **14**, July, 303–308). Improvements in pulse systems of ultrasonic flaw detection achieved at the National Physical Laboratory in the following three fields are described: the use of heavy, laminated low-velocity mode changer wedges, improvement of discrimination by the application of mechanical and electrical damping to the transducers, and the provision of beam systems which can be steered from selected sites to examine for flaws.—L. D. H.

Electronic Spectroscopy in the Soft X-ray Region. G. Shinoda, T. Suzuki, and S. Kato. (*Tech. Rep. Osaka University*, 1954, **4**, Mar., 1–5). A method and apparatus for the direct observation of soft X-ray spectra of solid surfaces on a C.R.O. are described and the findings of one experiment are briefly described.—J. G. W.

The Use of X-Rays in the Study of Metal Structures. J. L. De Almeida Bello. (*Bol. Assoc. Brasil Met.*, 1954, **10**, Apr., 155–181). [In Portuguese]. The techniques of micro-radiograph and X-ray crystallography are illustrated and discussed. Debye-Scherrer methods and apparatus are described, and the results for fixed and rotating specimens and back-reflection methods are compared. Faulty and correct techniques are illustrated. The apparatus for the X-ray study of orientation and fibre structures is also described.—P. S.

Industrial X-Ray Fluoroscopy with Particular Reference to Ultra-Fine Focus X-Ray Equipment. E. W. Kowol. (*J. Brit. Inst. Radio Eng.*, 1955, **15**, Feb., 101–109).

Radiographic Properties of X-Rays in the Two- to Six-Million-Volt Range. C. H. Goldie, K. A. Wright, J. H. Anson, R. W. Cloud, and J. G. Trump. (*Amer. Soc. Test. Mat. Bull.*, 1954, Oct., 49–54). The radiographic properties of 2 to 6 million V. X-rays have been studied, and, as expected, a large increase in radiographic speed and a lesser improvement in sensitivity as the voltage increases has been found. For the investigation of thick metal sections the optimum conditions are nearly always found in this voltage range. Further increase in voltage would not increase the use of the technique.

Discussion of Radiographic Characteristics of High Energy X-Rays. Transmission of X-Rays Through Steel-Megavoltage Range. D. A. Scag. (*Non Destructive Test.*, 1954, **12**, May-June, 45, 46 The author attempts to clarify the situation). which has arisen through many varied and often contrasting claims being made about the performance of various sized betatrons in industrial radiography. He concludes that any

betatron in the range of 15 to 30 mV. will give most of the advantages obtainable in megavoltage radiography, the actual choice of equipment probably being influenced by the mechanical features offered, and the type of suspension desired. (14 references).—P. M. C.

A New Magnetic Method for the Precision Gauging of Steel Sheets. (*Sheet Metal Ind.*, 1954, **31**, Nov., 906–908). A precision sheet thickness meter is described which employs the principle of saturation magnetization. A hand probe is applied to one surface of the sheet and its thickness is indicated in less than 0·1 sec. on a graduated precision scale. Absolute accuracy is better than 1% of full scale deflection. The instrument's calibration can be readily altered to cope with materials (such as silicon-steel) having different saturation magnetization compared with plain carbon steels. A small dry cell is the only power required.—P. M. C.

Practical Application of the Electromagnetic Induction Instrument ZETAP for Quality Control. A. Pokorný and J. Vašica. (*Hutník*, (Prague), 1954, **4**, (11), 332–338). [In Czech]. Construction and use of a sorting bridge with the output coupled to an oscilloscope (both of Czechoslovak manufacture) are described. The homogeneity of semi-finished goods, such as rods and tubes can be checked.—P. F.

The Influence of Air in the Measuring Gap on the Radioactive Method of Measuring-Density and Thickness. J. Reppisch and H. Repisch. (*Z.V.d.I.*, 1954, **96**, Nov. 21, 1135–1137). A correction factor is deduced for the effect of air in the measuring gap of instruments based on radioactive emission.—J. G. W.

Thermal Conductivity of Metals and Alloys at Low Temperatures. R. L. Powell and W. A. Blanpied. (*Nat. Bur. Stand. Circ.* 556, 1954, Sept.). An extensive compilation is given of the measured values of thermal conductivity of metals and alloys from room temperatures down to approximately 0° K.

On the Quality Testing of Steel Products by Supersonic Fault Locator. M. Yamashita and T. Kawai. (*Fuso Metals*, 1951, **3**, July, 174–182). [In Japanese]. Testing at 3 Mc. enables hair cracks, flakes, and other minor defects in large forgings to be easily located. For smaller special steel forged products, a frequency of 5 Mc. is suitable, and for large parts (e.g. axles, rolls or ingots) frequencies of 1–2 Mc. are used. Ultrasonic methods may be used to assist in evaluating the effects of austenitic grain size, heat-treatment, and cast structures.

Industrial Radiography and the Linear Accelerator. C. W. Miller. (*J. Brit. Inst. Radio Eng.*, 1954, **14**, Aug., 361–375: *Metro-Vick. Gaz.*, 1954, **25**, Dec., 468–478). The author first outlines the mechanisms of the absorption of radiation by matter. Minimum absorption is obtained with energies of the order of a few meV. For short exposure times a large X-ray output is required, and the energy is limited by the inherent lack of sharpness of the photographic image. It is shown that a linear accelerator operating at approximately 4 meV. gives optimum results.—L. D. H.

Applicability of Charpy Test Data. P. P. Puzak, M. E. Schuster, and W. S. Pellini. (*Welding, J.*, 1954, **33**, Sept., 433s–441s). Crack-starter tests were made and it was found that semi-killed and rimming structural steels have no ductility in the presence of a sharp crack of temperatures below that of the ductile-brittle transition temperature for the Charpy V-notch test at 10 ft-lb.—R. A. R.

Recent B.I.S.R.A. Work on the Elimination of Stretcher Strains in Mild-Steel Pressings. B. B. Hundy. (*Sheet Metal Ind.*, 1954, **31**, Nov., 909–920). The surface markings on mild steel pressings (stretcher strains or Lüders lines) are described and their correlation with the sharp yield point is discussed. An accelerated strain ageing test is described, and experiments undertaken to afford some correlation between residual stresses induced by rolling and the elimination of stretcher strains are described. Factors affecting the rate of return of the sharp yield point (stretcher-strain ageing) are discussed, including the effect of roll size on the efficiency of temper rolling and the effect of roller levelling on the ageing of temper rolled strip. (28 references).—P. M. C.

Review of Welded Ship Failures. H. G. Acker. (*Weld. Res. Council, Weld. Res. Council Bull. Ser.*, 1954, (19), Nov.) A critical review is presented of available information on structural failures in welded ships. Special consideration is given to the conditions under which a brittle-cleavage crack will start and propagate. Residual welding stresses and thermal stresses are discussed in an appendix.—U. E.

Crack-Starter Tests of Ship Fracture and Project Steels. P. P. Puzak, M. E. Schuster, and W. S. Pellini. (*Welding J.*, 1954, **33**, Oct., 481s–495s). The performance of rimmed and semi-killed steels involved in ship fractures was investigated by crack-starter tests. A sharp crack was introduced into the steel and the relative resistance to the initiation and propagation of fracture was established over the range of service temperatures. The steels had no appreciable ductility when the temperature falls below that of the Charpy 10 ft.lb. transition point. The propagation of brittle fractures becomes difficult at temperatures above the Charpy 15–25 ft.lb. transition points. With fully killed steel the propagation characteristics have to be related to higher Charpy values.

Metallurgical Considerations of the Problem of Cleavage Fracture. E. Houdremont and H.-J. Wiester. (*Arch. Eisenhüttenwesen*, 1954, **25**, Sept.-Oct., 435–446). The authors distinguish between fatigue fracture occurring at maximum load without plastic flow and the cleavage fracture occurring along a plane of the body-centred cubic α-iron crystal, usually after plastic flow. Plastic flow begins after the critical shear stress is exceeded; it is caused by the drift of dislocations in the crystal structure, thus forming new dislocations, resulting finally in cleavage fracture. The process is temperature-dependant. Cleavage fracture is also caused by twinning, usually effected by stress concentration in the twinning plane. High strain rate may cause elastic distortion of the crystal lattice which preceeds plastic flow. With decreasing temperature slip becomes more difficult and the lattice distorts elastically leading to cleavage fracture. Testing materials for a tendency to cleavage fracture is discussed. The tendency can be reduced by reducing impurities, e.g., phosphorus and sulphur, grain-refinement, and uniform dispersion of heterogenous inclusions.—T. G.

American Cold-Brittleness Tests and Their Effect on Brittleness Testing. K. Rühl. (*Arch. Eisenhüttenwesen*, 1954, **25**, Sept.-Oct., 421–433). This is a comprehensive review of American publications on the cold brittleness of steel. (44 references).—T. G.

Determination of the Thermal Properties of Metals with the Aid of Unsteady-State Heat Flow Processes, without Using Calorimetric Measurements. Shao-Ti Hsu. (*Eidgnöss. Techn. Hochschüle, Zürich*, 1954, Thesis No. 2324). Two methods are described of obtaining the thermal constants of various metals, including steel. In the first method the aperiodic temperature flow is measured in two thin plates of the metal brought rapidly together at different initial temperatures. In the second method the variations produced in a solid body by a periodic temperature oscillation are measured and evaluated. The theory, practical application, and evaluation of the methods are fully discussed.—L. D. H.

Effect of Temperature on the Stability of Wire Strain Gauges Fixed by Thermoplastic Adhesives. G. Faure. (*Recherche Aéronaut.*, 1954, July-Aug., 33–36). Errors arise during the measurement of stress with wire strain gauges which are fixed by thermoplastic adhesives if the temperature of the structure under examination varies. Thermosetting adhesives can be used but are difficult to employ. A method of minimizing temperature errors when thermoplastic adhesives are used has been developed and is described.—B. G. B.

Heat-Resisting Steels and Alloys. L. Wetternik. (*Radex Rundschau*, 1954, (3), Apr., 87–94). The composition of heat-resisting steels and alloys is surveyed and the effects of various alloying components is outlined. A comparison is made between German and American standards for rolled, forged, and cast steels. Adverse effects of W, Mo, and V_2O_5 are discussed and the influence of trace elements is considered.

The Resistance to Sulphuric Acid of Low-Nickel, High-Chromium Alloys with Molybdenum and Copper Additions. W. Tofaute and H. J. Rocha. (*Techn. Mitt. Krupp*, 1954, **12**, June, 67–72). Alloys with about 20–30% Cr, and up to 10% Ni, 3% Mo, and 3% Cu were annealed to their softest condition, and their mechanical properties, magnetic saturation, and corrosion resistance to nitric and sulphuric acids studied. Alloys containing 23–30% Cr and as little as 2–5% Ni showed a greater passivity region than the normal 18–8 alloys. Additions at the level of 2% Mo and 1% Cu could produce alloys superior in mechanical properties and passivity to the standard types of alloys.—L. D. H.

Internal Friction of Alpha-Iron due to Boron Atoms. R. R. Hasiguti and G. Kamoshita. (*J. Phys. Soc. Japan*, 1954, **9**, July-Aug., 646–647). Internal friction measurements supported the idea that boron atoms dissolve interstitially in alpha-iron. Diffusion coefficients and activation energies were

evaluated and are quoted together with those of nitrogen and carbon.—J. G. W.

On the Steel Tubes for High Temperature and High Pressure Boilers. G. Kojima, J. Omori, and S. Terai. (*Fuso Metals*, 1952, **4**, Jan., 241–251). [In Japanese]. The creep and other properties of ten alloy steels were investigated with a view to use in a new steam plant at 485° C. and 65 kg./sq. mm. After the tests, tubes of 1% Cr, 0·3% Mo steel were manufactured, and the properties of the tubes and the welded and rolled zones further examined; it is concluded that this steel is suitable for the service required.—K. E. J.

Development and Application of the SIGMA High-Tensile Steels. W. Jäniche, G. Peter, and C. Hücking. (*Tech. Mitt.*, 1953, (2), Dec., 57–75). The authors describe the development and uses of several self-hardening and heat-treated SIGMA tensile steels. Particular attention is paid to their application for the pre-stressing of concrete. The wires and rods are made in tensile strength ranges up to 92–102 tons/sq. in., SIGMA being the name given these steels by Hüttenwerk Rheinhausen A.G.—R. A. R.

The Errors Introduced into Diamond Pyramid Hardness Testing by Tilting the Specimen. T. O. Mulhearn and L. E. Samuels. (*J. Iron Steel Inst.*, 1955, **180**, Aug., 354–358). [This issue].

Some 12% Chromium Alloys for 1000° F. to 1200° F. Operation. D. L. Newhouse, B. R. Seguin, and E. M. Lape. (*Trans. Amer. Soc. Mech. Eng.*, 1954, **76**, Oct., 1107–1122). Detailed high-temperature (up to 1200° F.) creep-relaxation and stress-rupture data are given for 12%-Cr steels and six modifications including 12%-Cr–Co–W–V, 12%-Cr–W–V, 12%-Cr–Mo–V, 12%-Cr–Mo–W–V, 12%-Cr–Nb, and 12%-Cr–Ni–W. Thermal expansion, modulas of elasticity, and resistance to stress-corrosion are discussed.—D. H.

Creep Tests of Rotating Discs at Elevated Temperature and Comparison with Theory. A. M. Wahl, G. O. Sankey, M. J. Manjoine, and E. Shoemaker. (*J. Appl. Mech.*, 1954, **21**, Sept., 225–235). A programme involving methods of calculating creep in rotating discs at elevated temperature is described. Spin tests at 1000° F. for 1000 hr. were made on three forged and heat-treated discs from the same ingot of 12%-Cr. steel. Theoretical methods of calculation of creep deformation in such discs were investigated and a comparison made between the experimental and theoretical creep deformation of the discs using average tension-creep data. Available methods of calculating creep deformation of discs based on Mises criterion gave values lower than the experimental results. Better agreement between theoretical and experimental results was obtained if the former were based on maximum shear theory.—D. H.

The Optical Behaviour of Metals at Elevated Temperatures. G. Grass. (*Z. Metallkunde*, 1954, **45**, Sept., 538–547). The optical behaviour of a number of metals was investigated. The emissive power of iron at 10 μ between 600° and 950° C. shows clearly the influence of the Curie point and the α–γ transformation. In the visible range the reflective power of iron between 20° and 1200° C. is practically independent of temperature. Iron transformations are clearly recognizable from surface alterations and optical properties. Surface influences such as recrystallization and oxidation can be distinguished, and separated from the true temperature relationships of the optical properties.—L. D. H.

Brittleness on Heating of Extra-Mild Iron–Chromium Ferritic Steels. H. Laplanche. (*Mét. Constr. Mécan.*, 1954, **86**, Nov., 837–848). The problem of brittleness of this class of alloy is considered and their properties are presented in graphs and tables. The influence of additions of carbon, chromium, manganese, silicon, phosphorus, nitrogen, molybdenum, titanium and niobium on the brittleness is discussed. The formation and properties of the sigma phase and methods of etching specimens to bring out this phase are described.

The Influence of Previous Strain Hardening on Brittleness Due to Hydrogen in the Steel. P. Amiot, P. Azou, and P. Bastien. (*Compt. Rend.*, 1954, **239**, July, **12**, 164–166). The influence of the state of strain hardening of a steel before charging it with hydrogen, on the subsequent brittleness of the steel, is studied.—T. E. D.

Results of Creep Tests on Heat-Resisting Steels. H. Holdt. (*Z.V.d.I.*, 1954, **96**, Nov. 11, 1091–1098). The results of comprehensive creep tests on Cr–Mo and Cr–Mo–V heat-resisting steels, ranging from 20,000 to 30,000 hr., are reported in detail. In general, high alloy steels are more prone to brittle fractures at high loads than are low alloy steels. Steel composition dominates the behaviour of steels, the difference between treatments, e.g. whether cast or forged, being a minor effect. It is shown that short-term tests are not a reliable guide to performance in creep.—J. G. W.

The Effect of Oxygen on the Structure and Ageing of Pure Iron. F. Wever, W. A. Fischer, and H. Engelbrecht. (*Stahl u. Eisen*, 1954, **74**, Nov. 4, 1521–1526: *Iron Steel Inst., Translations Miscellaneous Series* 226). Metallographic examination of small ingots of hydrogen-reduced pure iron have shown that the solubility of oxygen in δ-iron at 1528° C. lies between 0·003% and 0·007%. The solubility decreases with falling temperature and is less than 0·003% in α-iron. Within the range investigated (0·004–0·10% oxygen) hardness does not depend on oxygen content, Brinell numbers being scattered between 55 and 58. The hardness of a specimen containing 0·073% of oxygen increased to 74 Brinell after quenching in water from 680° C. and tempering at 200° C., whereas no increase in hardness over the normalized value was observed at 0·007% of oxygen, after the same treatments. The hardness of critically strained specimens containing different amounts of oxygen did not change on annealing. The impact strength at room temperature decreased with increasing oxygen content. The tendency to brittle fracture was eliminated or markedly reduced by small increases of carbon content above 0·004%.—J. P.

Correlation Between Microstructure and Creep of Austenitic Chromium–Molybdenum–Nickel Steels. K. Bungardt and H. Sychrovsky. (*Stahl u. Eisen*, 1955, **75**, Jan. 13, 25–39). X-ray, metallographic and magnetic methods were used to determine the microstructures of 16/13 and 16/16 Cr–Ni steels containing up to 2·6% Mo. The molybdenum contributes to the formation of the sigma phase and replaces niobium in the intermetallic compound Fe_3Nb_2. Niobium does not promote sigma formation. Sigma phase and Fe_3Nb_2 tend to agglomerate above 600° C. Increasing nickel from 13 to 16% reduces all precipitation and diffusion phenomena and widens the gamma field at high quenching temperatures up to 1350° C. The sigma does not necessarily precipitate from the ferrite, but forms directly from the austenite. Molybdenum has a stronger effect on cold brittleness after quenching between 600 and 800° C. than has niobium; the inverse effect was found in hot brittleness. Age hardening increases with increasing molybdenum and niobium content. Recovery and recrystallization are observed above 700° C., this temperature increasing with increasing molybdenum. The steels can be cold-worked for improving their creep properties at temperatures up to 650° C. (18 colour micrographs are presented).

Effect of Alternating Stresses on Diffusion and Precipitation in Unalloyed Steel. H. Schenck and E. Schmidtmann. (*Arch. Eisenhüttenwesen*, 1954, **25**, Nov.-Dec., 579–588). Basic-Bessemer steel bars were subjected to alternating stresses while packed in a carburizing material in a furnace. The stressing increased the case depth. Ultrasonic vibrations at 430 kc./sec. and an output of 6·5 W./sq. cm. had the same effect. Nitriding and chromizing were also accelerated by alternating stresses. Ageing is greatly accelerated by pulsating stresses owing to the repeated lattice deformations.—T. G.

Electrical Properties of α-Fe_2O_3. F. J. Morin. (*Phys. Rev.*, 1954, **93**, Mar. 15, 1195–1199). The conductivity, Seebeck effect, and optical transmission of α-Fe_2O_3 have been analysed using two alternative models. The first model assumes conduction to occur in the *d* levels of iron ions and yields a quantitative fit to the data. The second model assumes conduction in the *sp* bands of oxygen in addition to *d*-level conduction; it is shown qualitatively to be a reasonable model.—R. A. R.

METALLOGRAPHY

Formation Energy of Superlattice in Ni_3Fe. II. Kinetics of the Superlattice in the Stage of Local Ordering. S. Iida. (*J. Phys. Soc. Japan*, 1954, **9**, May-June, 346–354). The change in internal energy of the Ni_3Fe superlattice during cooling was studied by means of specific-heat measurements. Local order begins to be formed at 600° C., proceeds at max. rate at 520° C., and is completed at 400° C. Local order formation was observable at 510° C. and decreased monotonously, ceasing after 5 hr. annealing.—J. G. W.

The Physical Background to Metallography. Å. Hentz. (*Värm. Bergsmann. Ann.*, 1953, 65–107). [In Swedish]. This lecture deals with the basic structure of the iron crystal lattice,

nature of grain boundaries, alloys and their formation as governed by atom configuration, phase transformation, deformation, and fracture.—G. G. K.

Electron Microscope provided with Intermediate Plate Chamber. E. Sugata and M. Tateishi. (*Tech. Rep. Osaka University*, 1954, **4**, Mar., 89–98). Details of improvements of electron microscopy are quoted and analysed in terms of performance.—J. G. W.

Microstructure of 18/8 Stainless Steel. Its Relationship with Electrolytic Polishing, Susceptibility to Intergranular Corrosion, and Passivation. P. A. Jacquet. (*Rev. Nickel*, 1954, **20**, Jan.-Feb.-Mar., 1–16). Methods of examination are briefly described, and results are given and discussed, with macro- and micro-photographs. Defects which occur in 18/8 stainless steel after industrial electrolytic polishing, but which are absent after polishing in an acetoperchloric acid bath, appear to be related to the precipitation of carbide along the grain boundaries. It is concluded that industrial electrolytic polishing of 18/8 steel is justified since corrosion resistance is improved in general, and a means of controlling intergranular corrosion is provided.—T. E. D.

Study of Anodic Tension during Polishing. P. Brouillet and I. Epelboin. (*Compt. Rend.*, 1954, **238**, May 31, 2160–2162). It is known that electrolytic polishing depends upon the adsorption on the metal surface of anions which create a very intense electric field. A reference electrode (calomel saturated with KCl) conveniently placed allows the potentials at the electrodes to be studied. It is shown that with anhydrous solutions, the diffusion potential is negligible compared with anodic potential. The production of a good polish is directly related to the value of the anodic potential.—G. E. D.

An Electron-Diffraction Study on Abrasion of Single Crystals of Metals. S. Nagata, Y. Tomoda, and H. Ide. (*Tech. Rep. Osaka University*, 1954, **4**, Mar., 7–19). Single crystals of silicon steel, beta-brass, and nickel were abraded uni-directionally and deformation structures at various depths were studied by electron diffraction. In general, rotational slip about an axis in the plane of abrasion and nearly perpendicular to the direction of abrasion was observed. The degree of rotation varied with crystal plane and direction of abrasion, and for the steel was in the range 20–30°.—J. G. W.

Direct Observations of Dislocations in Crystals. A. J. Forty. (*Advan. Phys.*, 1954, **3**, Jan., 1–25). A review is made of the experimental evidence justifying the idea of dislocation of crystal structure, including work on crystal growth, polygonization, slip bands, and bubble rafts. (49 references).—K. E. J.

Presentation and Significance of Grain Size Distributions. H. zur Strassen. (*Radex Rundschau*, 1954, (4–5), 143–151). [In German]. After discussing the correct presentation of a screen analysis the author studies the problem of linear or logarithmic presentation of interval division, together with weight and surface distribution. Equations are given for particle size distribution in accordance with the Gaussian law of error, whilst irregular distributions are shown by logarithmic indicating lines.—G. G. K.

The Effects of Inclusions or Imperfections on Magnetization Processes in Silicon-Iron. L. F. Bates. (*Brit. Elect. Allied Ind. Res. Assoc., Rep.*, 1954, Report N/T66). The author discusses and illustrates the special systems of closure domains set up in the immediate neighbourhood of an imperfection. The cases of an imperfection wholly within a principal domain and of a domain boundary passing through an inclusion are briefly considered. The sequences of events when 180° and 90° boundaries move across an inclusion are described, and it is shown that a small portion of a specimen which is in a state of strain can act as an imperfection.—L. E. W.

Solution of Graphite in Austenite. R. Kamenský. (*Slévárenství*, 1954, **2**, (12), 356–358). [In Czech]. Experiments with ferritic graphitic steels are described. Voids may be left by the solution of graphite nodules, as the space occupied by them is vacated more rapidly than it is filled. The eventual filling of the voids, if it takes place, is explained as a plastic deformation induced by the carbon in its local concentrated, solution.—P. F.

Heat Treatment of Dispersed System Magnet Steel. IV. M. Chubachi. (*Fuso Metals*, 1952, **4**, Jan., 256–261). [In Japanese]. In alloys containing 26–27% Ni and 15% Al, increases in Al and Co content reduce the critical cooling velocity, while Cu has the reverse effect. The velocity change is greatly influenced by the temperature of separation between α and α′ phases. The magnetic strength is weakened by the existence of γ phase, probably because of reduction of the α and α′ phases.—K. E. J.

The Transformation of the Steels by the Rapid Heating. IV. On the Ac_3 Transformation of the Armco Iron. K. Yokota and N. Iguchi. (*Waseda Univ., Rep. Castings Res. Lab.*, 1954, (5), 44–47). [In English]. Experimental results were obtained with an 'automatic dilatometer.' The Ac_3 point of Armco iron depends not only on heating rate but also on previous history, e.g. changes in grain size, and the 'imposed allotropy' hypothesis appears to be correct. The limited temperature range, however, may be due to the activity of carbon or other impurities.—K. E. J.

CORROSION

The Problem of Flaking and Corrosion Cracking of High Temperature Alloys for Use in Gas Turbines. P. Galmiche. (*Recherche Aéronaut.*, 1954, May-June, 45–53). An experimental study has been made of the corrosion of high-temperature alloys under the conditions prevailing in gas turbines. The influence of the gas composition has been investigated using a number of high-temperature alloys in the as-received condition and after chromizing. Complete combustion reduces the corrosion but does not eliminate it and increasing the chromium content of the surface increases the corrosion resistance.—B. G. B.

Marine Corrosion of Steelwork. G. Dechaux and E. Segol. (*Métaux–Corrosion–Indust.*, 1954, **29**, Dec., 469–482). Modern theories of corrosion are used to explain the practical results obtained since 1948 at the corrosion laboratory of Toulon Arsenal, France. The laboratory has been studying the corrosion of steel piles in sea-water. As a result cathodic protection and special anticorrosive paints are being successfully employed.—B. G. B.

Metallic Corrosion in the Baking Industry. F. J. H. Ottaway. (*Corrosion Techn.*, 1954, **1**, Nov., 322–327).

Lanolin Rust Preventives. G. F. Wood and A. C. Benson. (*Corrosion Techn.*, 1954, **1**, Nov., 328–329).

Corrosion Problems in Hospital Practice. S. J. Hopkins. (*Corrosion Techn.*, 1954, **1**, Nov., 330–332, 343).

Detecting Corrosion in Chemical Plant. H. Manley. (*Corrosion Techn.*, 1954, **1**, Nov., 333–335). The author introduces the principles of the ultrasonic thickness gauge and describes typical applications of the instrument.—L. E. W.

Corrosion in the Motor-Car. (2). The Cooling System. Z. S. Michalewicz. (*Corrosion Techn.*, 1954, **1**, Nov., 337–339). The author describes briefly the automobile cooling system and its operation with particular emphasis on the corrosion phenomena that may occur. The merits of various antifreezes and inhibitors are discussed.—L. E. W.

Laboratory Studies on the Use of Coal-Tar Bases as Inhibitors of Corrosion by Flue Gases. R. W. Kear. (*J. Appl. Chem.*, 1954, **4**, Dec., 674–679). In one series of tests, coal-tar bases were sprayed into a town-gas flame with the object of minimizing SO_3 formation; in another series the object was to deposit a protective film on the steel surface. Using gas flowing at 170 cu. ft./hr., containing 0·005% SO_3 (dew-point 138° C.), up to 12 g./hr. of bases reduced corrosion and sulphuric acid deposition rate at all temperatures below the dew-point. Deposition of a liquid film reduced corrosion below 117° C. but slightly increased it above the dew-point.—J. O. L.

Atmospheric Corrosion of Steel. K. F. Trägårdh. (*Tekn. Tidskr.*, 1954, **84**, Nov. 30, 1043–1047). [In Swedish]. The Swedish Corrosion Committee has undertaken exposure tests on 800 steel plates at eight sites under different atmospheric conditions. The plates were from 2 to 25 mm. thick, composed of seven grades of steel, and were set up in 1938. Details are given of test procedure, of mistakes subsequently established, steel pre-treatment, and rust evaluation using the Swedish Pictorial Rate. Tables show temperatures and rainfall at the sites and steel analyses.—G. G. K.

Tests on Protective Paint Coatings. P. Nylén. (*Tekn. Tidskr.*, 1954, **84**, Nov. 30, 1047–1053). [In Swedish]. A report is given of tests by the Swedish Corrosion Committee on 21 primers and 50 top coats, the main bases being red lead and white lead respectively. Sections deal with the influence of coating thickness on rust inhibition, climatic influences at the various test locations, and the effect of initial rust and plate preparation on corrosion. The superiority of zinc chromate over red lead primers is discussed. Tables show paint constituents and life spans, life as a function of coating thickness, and relative corrosion of wire-brushed and pickled plates.

The qualities of new materials such as polymerized oils, alkydes, chlorinated rubber, and PVC are also touched upon.—G. G. K.

Corrosion Tests with Unpainted Steel. K. F. Trägårdh. (*Tekn. Tidskr.*, 1954, **84**, Nov. 30, 1053–1056). [In Swedish]. Fifteen year exposure tests on unpainted steel plates by the Swedish Corrosion Committee aimed at determining weight losses due to inland and coastal atmospheres are reported. Results showed that corrosion decreased as the copper content rose, rusting of steel containing no copper being 20% greater. Tables indicate the weight losses of seven grades of steel and a comparison is made of the Swedish tests and similar BISRA exposures. The behaviour of galvanized plates is also reported.

Rust Progression. A. Härlin. (*Tekn. Tidskr.*, 1954, **84**, Nov. 30, 1057–1058). [In Swedish]. Test results obtained by the Swedish Corrosion Committee are evaluated and a comparison made with those achieved by B.I.S.R.A. exposures. Tables show weight losses of steel plates with and without millscale. Curves illustrate rust progression, loss of millscale, annual weight loss, and loss due to chemical derusting.—G. G. K.

The Protection of Steel Structures against Rusting. K. Krenkler. (*Werkstoffe Korrosion*, 1954, **5**, Nov., 441–451). This general review of the subject deals with: (1) Methods of surface preparation, including hand-cleaning, sandblasting, flame-cleaning, and chemical surface treatment; (2) the effect of the weather conditions at the time of painting; and (3) the merits of different painting schemes. The author considers that cold phosphoric acid surface washes are incapable of bringing rusty steel into a satisfactory condition for painting but regards wash primers as useful additions to painting technique. Paints in media containing chlorinated rubber and alkyd resin are to be preferred to paints in ordinary oil media for use on structures exposed to severely corrosive chemical atmospheres.—J. C. H.

The Protection of Buried Pipelines against Corrosion by Wrapping. W. Kirsch. (*Werkstoffe u. Korrosion*, 1954, **5**, Nov., 452–454). The author describes the use of wrapping materials to protect buried pipes against corrosion. These wrappings may consist of fibre, glass wool, or plastics and may be loaded with bitumen or grease; they are wound spirally on to the pipe with an overlap. When supplemented with cathodic protection, they yield excellent and lasting protection.—J. C. H.

The Attack of Silicon-Bearing Iron by Molten Zinc Saturated with Iron. D. Horstmann. (*Arch. Eisenhüttenwesen*, 1954, **25**, Nov.-Dec., 527–533). The loss of iron per unit area when attacked by molten zinc saturated with iron was measured as a function of time and temperature. With up to 1–1·5% Si there are temperature ranges in which the loss of iron is not proportional to time, but follows a parabolic law. This loss decreases with increasing silicon and the temperature at which the parabolic part of the curve begins rises at the same time. There is no parabola when the iron contains 4·86% Si.

Electricity Corrodes Ships' Engines. (*Electrical J.*, 1954, **153**, Oct., 1284). A short account of an investigation by Aktiebolaget Broströmes Linjeagentur into the corrosion of components of diesel engines is given. The corrosion is caused by the cylinders being negatively charged and the piston positively. The origin of this difference in polarity and methods of preventing the corrosion are briefly described.

Corrosion due to Mud Banks in River Estuaries. W. S. Patterson. (*J. Appl. Chem.*, 1954, **4**, Dec., 661–666). Estuary mud, which is frequently characterized by high bacterial pollution, is an environment in which corrosion of iron and steel may readily occur. The influence of temperature on the process has been examined, as has also the effect of abrasion on the protective quality of a paint film. Corrosion is very severe under the anaerobic conditions obtained by complete immersion. Under water-line conditions the phenomenon is more complicated, but corrosion under oxide blisters may be due to bacterial action. The presence of sulphide pollution of river mud-banks is widespread and occurs over extensive geographical areas.—J. O. L.

A Selection Guide to Corrosion-Resistant Cast Alloys. E. A. Schoefer. (*Machine Design*, 1954, **26**, Dec., 178–186). An attempt is made to provide guidance in selecting the most suitable cast alloy with regard to economy of fabrication and physical properties. It is based generally on typical properties to be expected from commercially obtainable materials, and on experience of the high-alloy foundry industry in the production and further fabrication of corrosion-resistant castings.—M. A. K.

Silicate Water-Treatment As a Means of Protecting Materials. G. Seelmeyer. (*Werkstoffe Korrosion*, 1954, **5**, Dec., 483–488). Conflicting results have been obtained when using sodium silicate in water to prevent the corrosion of metals by hot and cold waters. The author examines several documented cases of this treatment in Germany and other countries. At Essen the supply system was completely protected by a treatment which left about 17 p.p.m. of colloidal silica in the water. Combined additions of silicate and phosphate have been tried with conflicting results. Excessive additions of silicates may be harmful. The composition of the silicate used must be matched to the quality of the water, and the amount added carefully controlled to ensure film deposition rather than the removal of corrosion products.—J. C. H.

Corrosion Resistance of Carbo-Nitrided Steel. P. A. Clarkin and M. B. Bever. (*Metal Progress*, 1954, **66**, Dec., 108–109). Plain carbon-steel, carbonitrided under conditions which do not lead to the formation of compounds, corrodes in aqueous sodium chloride solution at the same rate both before and after carburizing. Wide variations in the carbonitriding conditions have no appreciable effect on the corrosion behaviour in this solution but the presence of carbon–nitrogen–iron compounds in the surface layer markedly improves its resistance. However, tests with sea-water suggest that the formation of a compound layer is undesirable.—B. G. B.

Painting for the Protection of Outdoor Metal Structures. J. F. Stanners. (*Corrosion Techn.*, 1954, **1**, Aug., 188–190; Sept., 239–242). The author deals with the surface preparations of steel, old steel, and non-ferrous metals and describes the effects of contaminants such as mill-scale, rust, oil, moisture, and dirt, on the protective efficiency of paint. Methods of cleaning the surfaces are described. The choice of paints, paint formulation, and the paint system are considered and how and when to apply the paint are discussed. He summarizes the steps that must be taken to ensure the successful protection of outdoor metal structures by painting.

Zinc-Rich Paints. C. Finlay and C. T. Morley-Smith. (*Corrosion Techn.*, 1954, **1**, Dec., 383–385). After defining the term 'zinc-rich paint' the authors discuss the problems of formulation, storage difficulties, the methods of applying such paints, their anti-corrosive properties, and their uses.—L. E. W.

Stainless Steels. J. Apraiz. (*Bol. Min. Indust.*, 1954, **33**, Oct., 543–548). [In Spanish]. After mentioning some earlier production of corrosion-resisting steels and their further development in the U.K., Germany, and the U.S.A., the author reviews the acid theory and the electrochemical theory of corrosion. The importance of the character of the oxide layer on the metal surface and the effect of temperature on corrosion are explained. Finally, Armco iron, and Toncan iron and steels containing 3–5% Cr are considered.—R. S.

Survey of Cathodic Protection in the United States. (*Corrosion et Anti-Corrosion*, 1953, **1**, May-June, 70–73; Sept.-Oct., 94–97; 1954, **2**, May-June, 127–132). Four bulletins published by the Correlating Committee on Cathodic Protection, sponsored by U.S. water, gas, petroleum, public services, railways, telephones, and the National Association of Corrosion Engineers, are reproduced. These bulletins consist of: (i) Directives for cathodic protection; (ii) reporting procedure; (iii) cathodic protection practice; and (iv) communal system of cathodic protection.

Corrosion Prevention Practice (No. 2). Protective Coatings for Cartridge Cases. (*Corrosion Prevention and Control*, 1954, **1**, Oct., 485–489, 491). The U.S. Naval Gun Factory specifications for the corrosion resistance requirements of steel cartridge cases are listed. The plating process selected for use at the Riverbank Ordnance Plant is described in detail. It consists of three basic functions: (i) Preparation of the surfaces for zinc plating; (ii) application of zinc by electrodeposition in an alkaline cyanide plating bath; and (iii) application of a zinc chromate conversion film to the surface of the zinc plate by electrolytic action.—L. E. W.

A Note on the Use of Electrode Potentials for the Estimation of Corrosion Due to Dissimilar Metal Contact. G. Mole. (*Brit. Elect. Allied Ind. Res. Assoc., Rep.*, 1954, Report O/T11). This report is intended to serve as a guide to the underlying principles governing the corrosion resulting from contact of dissimilar metals. It is pointed out that the electromotive series is suitable only for giving a rough indication of the corrosion occurring when dissimilar metals are in contact. Pourbaix's static equilibrium chart for iron in water is introduced and interpreted. The most important of other metal-electrolyte combinations for which static equilibrium charts

are available are listed. Pourbaix's incomplete dynamic equilibrium chart for iron in water is shown.—L. E. W.

Corrosion Control in Coil Spring Manufacture. C. Harris. (*Corrosion Techn.*, 1954, **1**, Dec., 376–379). The author discusses how the stress in a spring may be increased by corrosion. It is emphasized that steel is the most commonly used material. The possibility of stress-corrosion and corrosion arising from exposure to industrial atmospheres is considered and the protective coatings that may be used and their limitations and applications are described.—L. E. W.

Cathodic Protection in the Marine Field. W. G. Waite. (*Corrosion Techn.*, 1954, **1**, Sept., 229–232). The author describes how cathodic protection can be used at every stage of a ship's life from the fitting-out onwards. He also discusses the cathodic protection of other marine structures such as floating docks and buoys.—L. E. W.

Corrosive Conditions Encountered by Edge Cutlery. C. N. Kington. (*Corrosion Techn.*, 1954, **1**, Sept., 226–228). The range of cutlery steels in common use are discussed in relation to their corrosion resistance and cutlery properties. The cleaning of stainless cutlery is dealt with and particular attention is paid to the adverse effects of chlorine and chlorides. The electrochemical actions that can be set up in ordinary washing solutions and the useful applications of vapour phase inhibitors are indicated.—L. E. W.

Control of Corrosion of an Underground Irrigation Pipeline. B. H. Levelton and I. D. G. Berwick. (*B.C. Professional Eng.*, 1954, **5**, May, 15–18). The authors give the case history of the corrosion problems encountered in the Lakeview Irrigation Project and show how the corrosion (due to electrolytic action of local cells) has been drastically reduced by cathodic protection. The cathodic protection system is described. The cost of installation and maintenance for 10 years is estimated to be 26% of the cost of maintaining the same pipelines for the same period without corrosion prevention methods.

Corrosion Research Laboratories—1. The Corrosion Section of the British Non-Ferrous Metals Research Association. P. T. Gilbert. (*Corrosion Techn.*, 1954, **1**, Oct., 276–279). The author briefly reviews the activities of the Corrosion Section of the B.N.F.M.R.A. and indicates the sort of problems that are tackled.—L. E. W.

Corrosion Research Laboratories—2. The Contribution of the Tin Research Institute. S. C. Britton. (*Corrosion Techn.*, 1954, **1**, Dec., 372–375). The facilities of the Hot-Tinning and Tinplate, Electrodeposition, and Corrosion Laboratories of the Tin Research Institute are briefly described and their activities are outlined.—L. E. W.

ANALYSIS

The Spectrum of Steel. A Table for the Selection of Homologous Spectral Lines. J. Convey and J. K. Hurwitz. (*Dept. of Mines and Techn. Surveys, Mines Branch, Canada*, Report 848). A large number of iron and alloying lines in steel are listed in the wavelength range 2327–4383 Å., the excitation potential and visual intensities being given for each line, and a final column giving interfering lines, based on the dispersion obtained in the Hilger large-dispersion quartz spectrograph. The main purpose of this classification is to facilitate the selection of homologous line pairs by choosing lines with similar excitation potentials.—L. D. H.

Quantitative Analysis of Steel and Iron with the Quantometer. H. Yoshinaga, S. Fujita, and S. Minami. (*Tech. Rep. Osaka University*, 1954, **4**, Mar., 21–31). A quantometer constructed by the authors is described, and results are quoted of the analysis of Si, Mn, Cu, Ni, Cr, Ti, Al, Mo, As, Sn, C, and P in steel samples and of Mg in iron samples. Long-term reproducibility was checked for Mn and C, and was found inferior to short-term performance, suggesting shortcomings of spark source. Otherwise, however, the quantometer compared favourably with photographic spectrochemical analysis.

A Simple Method of X-Ray Analysis of the Elements Ti(22) to Zn(30). H. Herglotz. (*Radex Rundschau*, 1954, (6), Aug., 194–202). A thin target X-ray tube is used for fluorescence spectrum analysis in conjunction with a non-rotating back-reflection camera. The equipment is described in detail and results are given for a number of metals, including Fe, Mn, Ni, Cr, etc.—E. C.

On the Quantitative Determination of Micro-constituents in Steel by Lineal Analysis Method. T. Kawai. (*Sumitomo Metals*, 1953, **5**, July, 128–134). [In Japanese]. Statistical methods have been used to study the errors introduced by the apparatus, heterogeneity, the observer, etc., in the lineal analysis method of Cohen and Robert, as applied to various normalized and as-forged carbon steels. Studies were also made on prints and on grain sizes after transformation.—K. E. J.

The Method of Transfer to a Secondary Electrode and Its Application to the Spectroscopic Analysis of Elements in High Concentrations. F. Malamand. (*Recherche Aéronaut.*, 1953, Mar.-Apr., 51–58). In this method of analysis the deposit formed on an electrode by passing a H.F. spark on to the material to be analysed is used as the sample for spectroscopic examination. The method is useful for certain elements in high concentration (80–90%) and it has been used with success for chromium in Co–Cr, Fe–Cr, Ni–Cr alloys, for nickel in Fe–Ni alloys, and for nickel and chromium in stainless steels of the 18/8 type.—B. G. B.

Microspectroscopic Analysis of Metals and Alloys. J. Descamps. (*Recherche Aéronaut.*, 1953, Mar.-Apr., 39–49). A description is given of spectroscopic qualitative and quantitative analysis of the areas on metal samples of the order of 0·02–0·05 mm. in diameter. Some examples of the application of the techniques are cited.—B. G. B.

Rapid Method for the Determination of Oxygen in Solid Steel. F. Kordon and A. Schmid. (*Hüttenwerk Oberhausen A.G., Technische Berichte*, 1951/54, Paper No. 13). A modified vacuum-fusion method is described for the determination of oxygen in steel by measuring the volume of CO evolved. The amount of CO_2 produced is negligible, but the nitrogen and hydrogen present must be known and allowed for. The possible influence of other elements is discussed. With a 5-g. sample about 30 determinations can be carried out in 7 hr.

Estimation of Alkali Metals by Flame Spectrophotometry. A. Roynette and J. Baron. (*Publ. Inst. Rech. Sid.*, Série **A**, 1954, (78), May, 12 pp.). Determination of sodium and potassium are described, with particular reference to the influence of interfering ions, namely Al, Fe, Ca, and Mg, encountered in the analysis of refractory materials. A method is proposed for the precise estimation of alkali metals in the presence of interfering ions, without their elimination. The theoretical basis of the method is supported by experimental results.—T. E. D.

Study of the Colorimetric Determination of Aluminium in Steels. M. Jean. (*Anal. Chim. Acta*, 1954, **10**, June, 526–553). [In French]. The investigation led to the development of a method consisting of electrolysis with a mercury cathode, separation of titanium and vanadium, if present, by chloroform extraction of the complexes of these elements with cupferron, and finally, colorimetric determination of aluminium. The influence of several elements on the reaction of aluminium with the new reagent stilbazo was also studied.

Improvements of the Method for Microcarbon Analysis of Industrial Pure Iron. T. Fujii. (*Fuso Metals*, 1951, **3**, Apr., 88–93). [In Japanese]. Improvements to methods of Yensen and Ziegler are made by using high-purity electrolytic oxygen, mercury cut-offs instead of greased taps, and flowmeters to regulate the evacuation velocity of the CO_2.—K. E. J.

Conductometric Determination of Carbon in Low-Carbon Steels. R. Pulpán and M. Kroupa. (*Hutnické Listy*, 1954, **9**, (11), 674–676). [In Czech]. Carbon dioxide liberated by combustion of the suitably prepared sample is used to precipitate barium carbonate from a barium hydroxide solution. The conductivity of the latter decreases as a consequence of the reduced ion concentration, the decrease being a measure of the amount of carbon oxidized. Equipment, procedure, and accuracy are considered.—P. F.

The Determination of Nickel with Dimethylglyoxime in the Presence of Iron and Cobalt. E. E. Byrn and J. H. Robertson. (*Anal. Chim. Acta*, 1955, **12**, Jan., 34–37). [In English]. A method is described for the determination of nickel with dimethylglyoxime, the co-precipitation of iron and cobalt which takes place when both these elements are present together being prevented by chelating with a 47% solution of N, N–Dihydroxyethylglycine. Chelation of nickel is prevented by the addition of zinc chloride. *p*H values up to 11 may be used.—L. D. H.

A New Photometric Determination of Nickel using Ethylenediamine Tetra-Acetic Acid. W. Nielsch and G. Böltz. (*Anal. Chim. Acta*, 1954, **11**, Oct., 367–375). [In German]. A method is described for determining nickel by complexing with ethylenediamine tetra-acetic acid. The extinction is measured in the range 580–750 mμ, the solution being buffered to a *p*H of 4·55–6·82. Ammonium salts tend to interfere. The curve

is linear over a nickel range of 40–5000 mg./ml.; the method can be used for the analysis of nickel-rich alloys.—L. D. H.

Coulometric Titration of Zinc With Ferrocyanide. J. J. Lingane and A. M. Hartley. (*Anal. Chim. Acta*, 1954, **11**, Nov., 475–481). [In English]. A method is described for the automatic coulometric titration of zinc ion with ferrocyanide ion generated by the reduction of ferricyanide ion at a platinum cathode.—T. E. D.

Sampling of Liquid Steel to Determine Hydrogen. S. Bergenfelt and L. Bjerkerud. (*Jernkontorets Ann.*, 1954, **138**, (12), 750–758). [In Swedish]. An investigation was made to study the influence of sampling time on the determination of hydrogen, comparative tests being made with two different methods. Results show that sampling time is extremely important, but that the time during which the test piece is kept in solid CO_2 (24 hr.) does not influence the analysis. The comparison was made between a casting method, with subsequent protection of the sample in solid CO_2, and an absorption method in which the sample is kept in mercury. The latter method was not so suitable.—G. G. K.

Determination of Gases in Iron by Vacuum Melting. L. Špaček. (*Hutnické Listy*, 1954, **9**, (12), 705–711). [In Czech]. Existing methods of gas determination in metals are critically surveyed. Equipment designed by the author, in which the samples are induction heated to temperatures up to 2000° C. *in vacuo*, is described, and a statistical anaylsis of the probable errors in this method is made.—P. F.

Study of the Application of *iso* Nitrosomalonylguanidine to the Estimation of Iron in Aluminium Alloys and in Zinc, and to the Estimation of Cobalt in Steels. M. Jean. (*Anal. Chim. Acta*, 1954, **11**, Nov., 451–462). [In French]. *Iso* nitrosomalonylguanidine reacts with iron salts in acid medium (*p*H 6) or in basic medium (*p*H 9) giving a blue colour. The methods for iron in aluminium or zinc are described. For the determination of cobalt in steel, bromine can be used instead of nitric acid, which was used previously, to decompose the excess of reagent and the iron complex.—T. E. D.

Notes on the Direct Determination of Combined Oxygen in Metals and Metal Oxides. II—Determination of Oxygen in Metal Oxides. E. Eberius and W. Kowalski. (*Z. Erz. u. Met.*, 1954, **7**, Aug., 339–343). A detailed account and discussion are presented concerning a method of direct determination of oxygen in oxides and carbonates. The method relies on solution with hydrochloric acid plus glacial acetic acid, followed by titration.—E. C.

Estimation of Several Minor Elements in Lorraine Iron Ores. G. Laplace. (*Publ. Inst. Rech. Sid.*, Series **A**, 1952, (41), May, 1–61). Brief descriptions are given of the isolation of trace elements by precipitation, solvent extraction, or distillation. The principles of the methods of estimation, namely spectrophotometry, polarography, and flame spectrophotometry, are also given. These methods, as used in the determination of traces of chromium, nickel, cobalt, copper, zinc, lead, potassium, and sodium, are described. Tests are given for the detection of cadmium, tin, and germanium.

A New Method for the Rapid Determination of Calcium in Magnesites. H. Flaschka and H. Jakobljevich. (*Radex Rundschau*, 1954, (3), Apr., 83–86). A new rapid volumetric method is described, based on the use of 'Komplexon' and on masking of sesquioxides with triethanol amine, magnesium being precipitated with caustic soda. A concise account describes all details of the method.—E. C.

On Rapid Analysis of SiO_2 in Moulding Sand. S. Nishida. (*Sumitomo Metals*, 1953, **5**, Oct., 220–224). [In Japanese]. Rapid analysis of SiO_2 may be effected by treatment with HF and volatilization. To remove errors in this method, HNO_3 and H_2SO_4 should be added to the HF, and an accurate analysis may be obtained within 2 hr.—K. E. J.

INDUSTRIAL USES AND APPLICATIONS

The Metallurgy of Hot-Formed Springs. W. O. Beale and C. G. Lowth. (*Aust. Inst. Met. Conference; Australasian Eng.*, 1954, Aug. 7, 54–58). The merits of the various grades of steel normally used in Australia are considered with particular reference to springs made from hot-rolled bar. The metallurgical aspects of steelmaking, rolling, and spring manufacture are briefly discussed together with the metallurgical characteristics of finished springs in relation to their service requirements.—P. M. C.

On the Results of Practical Tests of Steel Materials for Catalyst Container Tubes of Ammonia Converters (I). K. Takehara. (*Sumitomo Metals*, 1953, **5**, July, 123–127). [In Japanese]. Tests were made in service conditions at 400–500° C. and 300 kg./sq. cm. for 107 days. Carbon and nickel steels and 1% Cr–Mo steel lost carbon and absorbed nitrogen through the section. 1% Cr, 0·8% V steel formed a cracked nitrided case. 3% Cr, 0·8% V, 0·6% Mo steel and 5% Cr, 0·2% Mo steel formed thin nitrided cases without cracks, but the best results were given by 18/8 stainless steel.—K. E. J.

Study on the Materials of Gas Turbine Wheels (I). T. Hasegawa and O. Ochiai. (*Sumitomo Metals*, 1953, **5**, Oct., 206–212). [In Japanese]. Tests were made on ferritic stainless steels, 18/8, steel and modified 18/8 super-alloys with a view to suitability for use in rotors. Tensile strengths, ductilities, and the effects of swaging are reported.—K. E. J.

Heat Resistant Alloy Castings in the United States: Properties and Uses. G. F. Geiger. (*Rev. Nickel*, 1953, **19**, Oct.-Nov.-Dec., 79–89). Alloy grades are listed giving their chemical compositions and also their mechanical properties in the range 540–1090° C. Physical properties and resistance to corrosion by various atmospheres and molten metals are also described. Uses are recommended for the various alloys.—T. E. D.

Problems of Corrosion Resistance in the Food Industry and Nickel Alloys. (*Rev. Nickel*, 1953, **19**, Oct.-Nov.-Dec., 92–98). The use of Inconel, pure nickel, Monel, or 18/8 stainless steel in equipment for processing food and drink, is surveyed. Effects of various organic acids encountered in preserving, brewing, and dairying are mentioned.—T. E. D.

The Use of Steel in Pressure Pipes. D. Cecchi. (*Costruzioni Met.*, 1951, **3**, Nov.-Dec., 21–26). [In Italian.] Developments in the uses of steel for pressure pipes since the war are reviewed. The first important step came when permissible working stresses were raised from 37 kg./sq. mm. to 48 and even 54 kg./sq. mm. The second advance came about with improved welding techniques.—M. D. J. B.

Rock-Drilling with Hard Metals. II. E. J. Sandford and J. R. Wiles. (*Alloy Metals Review*, 1954, **8**, June, 2–8). The choice of suitable grades of hard metal for tipping rock drills, the choice of steel for stems, and the problems of brazing the tip to the steel stem are discussed.—V. G.

Alloys for Turbo-Machines. (*Aciers Fins Spéc. Franç.*, 1954, June, 47–50). The properties of heat-resisting alloys for use in gas turbines are discussed, and details given of the three main groups used, i.e. ferritic steels, austenitic alloys, and structurally hardened austenitic alloys and derivatives.

On the Evolution of Gases from the Metal Sheets for Vacuum Tube. T. Saito. (*Fuso Metals*, 1950, **2**, July, 156–162). [In Japanese]. Tests were made with nickel, iron, nickel-clad, and aluminium-clad sheets with a view to determining their suitability for use in vacuum tubes; the evolution of gas (CO, CO_2, and H_2) was least with pure nickel, but most rapid at all temperatures. In all metals, hydrogen treatment decreases gas evolution, and it is increased by oxides on the surface.—K. E. J.

ECONOMICS AND STATISTICS

The Place of the Piassaguera Works in the Brazilian Iron and Steel Industry. E. Macedo Soares e Silva. (*Eng. Min. e Met.*, 1954, **20**, Oct., 177–179). [In Portuguese]. The economics and industrialization of Brazil with particular reference to iron and steel are discussed. Production and import figures for steel are quoted from 1921 to 1953. Details are given of the iron and steel producing plant being built at Santos Piassaguera, the second phase of which will be complete in 1960.—P. S.

The Klement Gottwald New Iron and Steel Works as an Expression of Technical Progress in Czechoslovakia. W. Sajch. (*Przeglad Techniczny*, 1954, (12), 444–445). [In Polish]. A brief description of the 'New Iron and Steel Works' comprising coke-ovens, sintering plant, two blast-furnaces, O.H. furnaces, rolling mill, and a forge for heavy forgings is given. The interesting points mentioned are: coke is made from precompressed coal charges, and one of the blast-furnaces is spray-cooled and has a lining of only one-third of the normal thickness. No technical data are given.—V. G.

Recent Developments in the Iron and Steel Industry of Great Britain. A. Post. (*Berg. Hüttenmänn. Monatsh.*, 1954, **99**, Aug.-Sept., 141–149). A broad survey is made of all aspects and activities of the British iron and steel industry, covering developments since 1945. Brief outlines are given of new processes and methods in ore preparation, ironmaking, and

steelmaking. Organization and planning are discussed and the system of research and information services is described.

USINOR. (*Aciers Fins Spec. Franç.*, 1954, June, 123–126). A brief description is given of the six works belonging to the Union Sidérurgique du Nord de la France (USINOR) with their products and the proposals for new rolling-mill capacity.

The Iron and Steel Industry as an Essential Element in the Development of Industrial Life in Spain. E. Merello Llaseras. (*Bol. Min. Indust.*, 1954, **33**, Nov., 585–610). [In Spanish]. Part I deals with the history of the Spanish iron and steel industry up to 1900. Part II covers the period 1900 to 1938. Part III reviews progress from 1938 to the present day. Details are given of expenditure on plant and some new plants are listed without technical descriptions. Output figures for pig iron and steel planned for 1958 to 1960 are stated. The author discusses factors influencing the consumption of iron and steel products and surveys the possibilities of the various steelmaking processes in Spain and the quantities of raw materials required.—R. S.

Productivity, Fuel Availability and Its Efficient Use. K. T. Spencer. (*Engineer*, 1954, **198**, Dec. 24, 889–891; Dec. 31, 923–925). This paper, presented at a D.S.I.R. Conference on Research and Industrial Productivity, held from Nov. 22 to 25, 1954, gives facts about the present fuel and power situation and how that situation has come about.—M. D. J. B.

The First Large Soviet Mill. L. Andrejev. (*Hutnik*, 1954, **21**, (12), 408–415). [In Polish]. A description of a large rolling mill which was built entirely in the U.S.S.R. is given. The products made by this mill include rails with tensile strength up to 80 kg./sq. mm., 12·5–25 m. long (weight 43–75 kg./m.) beams and other heavy sections with strengths up to 60 kg./sq. mm.—V. G.

MISCELLANEOUS

Iron and Steel Industry and Automatic Control. Y. Takahashi and Y. Oshima. (*Tetsu to Hagane*, 1954, **40**, Nov., 1080–1084). [In Japanese]. A review is given of the basic principles of automatic control, types of mechanism, and the design of control systems. Applications to O.H. furnaces and soaking pits are described, with reference to control of temperature, pressure, and fuel flow.—K. E. J.

The Science of Mathematical Statistics and the Possibilities of Its Application in the Iron-Producing Industry. H. Gobiet and K. Schnick. (*Hüttenwerk Oberhausen A.G., Technische Berichte*, 1951/54, Paper No. 20). The elements of mathematical statistical theory are outlined, applications of the method to iron and steel production are suggested, and the limitations of the technique pointed out.—L. D. H.

Inspection—Its Relation to Operational Research. E. D. van Rest. (*Operational Res. Quart.*, 1954, **5**, Sept., 60–66). The reasons for inspection of the end-products of any operation and the principles on which such inspection should be organized are discussed. The organization and techniques required for inspection are stated.—J. E. J.

Automatic Recording and Analysis of Data Using Teleprinter Technique. D. F. Nettell. (*Instrument Practice*, 1954, **8**, Nov., 975–980; Dec., 1078–1082). The author describes a method in which data can be automatically recorded and analysed with great rapidity, using commercially available equipment.—R. A. R.

Attenuation of Vibrations by Leaf Springs—Reducing Inter-Leaf Friction. A. J. King. (*Engineering*, 1954, **178**, Dec. 31, 856–857). The resilient mounting on leaf springs of a tall fragile structure near a steam-hammer is described. The poor attenuation of vibration obtained was traced to a natural frequency of 6 O/S instead of 1·1. The ratio of 30 times between the dynamic and static stiffnesses of the springs was due to interaction between the leaves and was eliminated by inserting rubber sheeting.—M. D. J. B.

The Prevention of Industrial Accidents. (*Aciers Fins Spéc. Franç.*, 1954, June, 16–23). The consequences of accidents from the national and employers' point of view are discussed, together with ways of developing safety-consciousness. Reference is made to the work of the safety committees in the Longwy region, and the duties of a safety engineer are defined. Figures for the incidence and gravity rate of accidents in the French iron and steel industry show an improvement of over 40% in the last ten years.—E. A. C.

BOOK NOTICES

BAKER, C. "*Technical Publications. Their Purpose, Preparation and Production.*" 8vo, pp. xiii + 302. Illustrated. London, 1955: Chapman and Hall, Ltd. (Price 36*s.*).

This volume gives a comprehensive and readable account of the preparation and production of the many forms of technical publication needed by modern industry. The author's long experience as the head of the technical publications department of a large aircraft company ensures that his selection of material and his proferred advice are realistic and based on well-tried practice.

The emphasis of the early chapters is on the importance of designing publications to meet the needs of the intended readers; a technical document, however trivial and short-lived it may be, is viewed as an instrument which, like any mechanical instrument, can be designed to meet its purpose efficiently. There follows detailed and helpful guidance on the use of words and visual aids in speeding readers' perception and understanding. The more mechanical operations of duplicating and producing papers are then discussed with due concern for comparative costs. The last two chapters are confined to problems of particular importance to the aircraft industry, among them the eliciting of technical information from specialist departments; but this is a general problem and the advice given is more widely applicable than the author claims for it.

The book must be regarded as a general survey rather than as an exhaustive treatise; its value lies in its breadth, its balance, and its wise counsel rather than in its depth of detail. Its many illustrations are helpful and well-chosen, but though they doubtless add greatly to its cost of production they do not entirely excuse its high price.

B. C. BROOKES.

CAZAUD, R. "*Le Frottement et l'Usure des Métaux: les Anti-Frictions.*" Préface de J. Cournot. 8vo, pp. xii + 221. Illustrated. Paris, 1955: Dunod. (Price 2250 fr.).

The scope of this work is perhaps a little different from that suggested by the title, since the subject of bearings is dealt with in all its aspects. The first chapter comprises a fairly general discussion, including theory of solid friction and lubrication and the various manifestations of wear. The author then brings out the desirable properties of bearing materials, and describes the various laboratory tests which can be made to assess their suitability for particular functions. Six chapters are devoted to detailed consideration of the various types of bearing alloy, grouped according to the major constituent element, while two others describe the application of the techniques of powder-metallurgy and electrolytic deposition to bearings. Manufacturing processes are detailed in the last chapter.

The work has been compiled very largely from brief abstracts of papers published in the technical press of Europe and America. Inevitably this method, coupled with the plan of the book, has led, on the one hand, to a good deal of repetition, and, on the other, to the inclusion of some mutually contradictory statements.

Though the research worker interested in the fundamentals of friction and wear of metals will find this treatise elementary and may utilize it principally as a source of references, it will undoubtedly prove valuable and instructive to a large body of practical engineers. A comprehensive table of contents compensates for the lack of a subject index; the few errors noted (e.g. an inverted expression for mean pressure on p. 10) are readily detected or unimportant. More serious is the fact that occasionally the brevity, generally commendable, can convey an ambiguous or even erroneous impression.

The quality of reproduction of half-tones and line diagrams, print, and layout give the book an excellent appearance.—A. J. FENNER.

CLARK, GEORGE L. "*Applied X-rays.*" Fourth edition. (International Series in Pure and Applied Physics.) 8vo, pp. ix + 843. New York, Toronto, London, 1955: McGraw-Hill Book Co., Inc. (Price 89*s.* 6*d.*).

Professor Clark, in his preface to this the 4th edition of "Applied X-rays," comments on the tremendous expansion of the practical application of X-rays since his early

missionary work with the 1st edition in 1926, and raises the question as to whether any one author can now hope to cover the whole field. The solution may well be as he suggests in having a group of specialists in various fields expertly edited in a joint work. For the present, however, Professor Clark demonstrates again his ability to fill that multiple role. Nevertheless, the same expansion of the field also raises the question of for whom such an all-embracing book is now intended. From the particular point of view of the metallurgist there is much in this work which is extremely relevant, namely, the sections dealing with the diffraction studies which yield information of structures, alloys, and textures of metals, together with some mention of radiographic work. Furthermore, there are valuable chapters on crystal chemistry, silicates, and amorphous materials which have a close connection with metallurgy. Throughout the book much new material has been added, and on both techniques and results the book is thoroughly up-to-date.

There is, however, as much in the book which the metallurgist will hardly require and may not read, unless, as is only too likely, his attention is caught by an illustration or a heading while turning the pages to a more familiar topic. In this case only good can result.—E. A. CALNAN.

" *Metallurgical Progress. A Series of Critical Reviews*," and " *Metallurgical Progress—2. A Second Series of Critical Reviews.*" La. 4to, pp. 80 and 67. London, [1955]: " Iron and Steel." (Price 4*s.* 6*d.* each).

These publications consist of reprinted articles from the journal *Iron and Steel*. The first contains " Ironmaking," by John Taylor; " Steelmaking Reactions," by P. T. Carter; and " Solidification of Steel," by T. B. King, which appeared in the Feb., 1953, to Jan., 1955, issues of that journal and were abstracted in *J. Iron Steel Inst.*, 1953, vol. 174, p. 395; 1954, vol. 176, p. 455; 1954, vol. 177, p. 462. The second contains " Preparation of Ores," by J. M. McLeod; " Electric Steel Production," by D. D. Howat; and " Non-Metallic Inclusions," by H. B. Bell, which appeared in *Iron and Steel* between Feb. and Oct., 1954; the first paper was abstracted in *J. Iron Steel Inst.*, 1955, vol. 179, p. 84; abstracts of the other two are in the press.

The two publications provide a very useful description of modern theories of iron and steelmaking for those who did not see the articles on their first appearance.—J. P. S.

NEW PUBLICATIONS

AMERICAN IRON AND STEEL INSTITUTE. " *Railway Track Materials.*" (Steel Products Manual.) Revised April, 1955. La. 4to, pp. 93. Illustrated. New York, 1955: The Institute.

American Society for Testing Materials, Proceedings, vol. 54, 1954. Committee Reports, Technical Papers. 8vo, pp. xii + 1412. Illustrated. Philadelphia, Pa., 1955: American Society for Testing Materials. (Price $12.00).

BRITISH STANDARDS INSTITUTION. B.S. 938: 1955, " *General Requirements for the Metal-Arc Welding of Weldable Structural Steel Tubes.*" 8vo, pp. 21. Illustrated. London, 1955: The Institution. (Price 4*s.*).

BRITISH STANDARDS INSTITUTION. B.S. 2594: 1955. " *Horizontal Mild Steel Welded Storage Tanks.*" 8vo, pp. 27. Illustrated. London, 1955: The Institution. (Price 4*s.*).

BRITISH STANDARDS INSTITUTION. B.S. 2597: 1955. " *Glossary of Terms used in Radiology.*" 8vo, pp. 82. London, 1955: The Institution. (Price 10*s.*).

BRITISH STANDARDS INSTITUTION. B.S. 2600: 1955. " *British Standard General Recommendations for the Radiographic Examination of Fusion Welded Joints in Thicknesses of Steel up to 2 Inches.*" 8vo, pp. 21. Illustrated. London, 1955: The Institution. (Price 4*s.*).

CONSERVATOIRE NATIONAL DES ARTS ET MÉTIERS. " *Formation du Grain dans les Métaux par Crystallisation.*" Semaine d'Etude de la Physique des Métaux. Organisée avec le patronage de la Société Française de Metallurgie. La. 4to, pp. 123. Illustrated. St. Germain-en-Laye, [1955]: Editions Métaux. (Price 1500 fr.).

" *Die Eigenschaften der wichtigsten Baustahle.*" GOST-Normen. Zusammensetzung, Eigenschaften und Verwendung der wichtigsten Stähle im Tab. dargestellt. Kap. X aus: Der Maschinenbau. Enzyklopädisches Nachschlagewerk. Bd. 3. Übersetzung aus dem Russ. 4to, pp. 220. Berlin, 1954: Die Wirtschaft. (Price DM. 17.–).

EULER, HANS, and HANS STEVENS. " *Die Analytische Arbeitsbewertung als Hilfsmittel zur Bestimmung der Arbeitschweirigkeit.*" Unter Mitarbeit des Fachausschusses " Arbeitstudien, Arbeits- und heistungsbewertung." 3. Auflage. (Socialwirtschaftliche Schriftenreihe. Herausgegeben vom Ausschuss für Sozialwirtschaft der Wirtschaftsvereinigung Eisen- und Stahlindustrie, Heft. 3.) Folio, pp. 87. Dusseldorf, 1954: Verlag Stahleisen m.b.H. (Price DM. 9.60).

EUROPEAN COAL AND STEEL COMMUNITY. THE HIGH AUTHORITY. " *Third General Report on the Activities of the Community (12th April 1954 to 10th April 1955).*" 8vo, pp. 186. Illustrated. [Luxemburg], 1955: European Coal and Steel Community.

GRÖBER, H., and S. ERK. " *Die Grundgesetze der Wärmeübertragung.*" Dritte vollig neubearbeitete Auflage von Dr.-Ing. Ulrich Grigull. La. 8vo, pp. viii + 428. Illustrated. Berlin, Göttingen, Heidelberg, 1955: Springer-Verlag. (Price DM 37.50).

HENTSCHEL, WALTER. " *Kursächsischer Eisenkunstguss.*" (Forschungen zur Sachsischen Kunstgeschichte, Bd. 4.) 8vo, pp. 315. Illustrated. Dresden, 1955: Wolfgang Jess Verlag. (Price DM. 21.–).

IRON AND STEEL INSTITUTE. " *Index to the Publications of The Iron and Steel Institute (Journals, Special Reports and Bibliographical Series), 1941–1945.*" 8vo, pp. iii + 524. London, 1955: The Institute. (Price 10*s.* 6*d.*).

IRON AND STEEL INSTITUTE. " *Symposium on Sinter.*" (Iron and Steel Institute Special Report No. 53.) La. 4to, pp. vii + 200. Illustrated. London, 1955: The Institute. (Price 37*s.* 6*d.*; Members 25*s.*).

MEURICE, ALBERT, and CHARLES MEURICE. " *Analyse des Matières Minérales.*" 4e edition. Pp. 981. Illustrated. Liège, 1954: Ed. Georges Thone.

NEUMANN, BERNHARD. " *Die älteste Verfahren der Erzeugung technischen Eisens durch direkte Reduktion von Erzen mit Holzkohle in Rennfeuern und Stücköfen und die Stahlerzeugung unmittelbar aus dem Eisenerz.*" Mit einem Nachwort von Helmut Wilsdorf. (Freiburger Forschungshefte. Reihe D. Kultur und Technik. H.6.) 8vo, pp. 107. Berlin, 1954: Akademie-Verlag. (Price DM. 7.–).

OIKS, G. N. " *Giessgrubentechnik am Siemens-Martin-Ofen.*" Metallurgie des Stahls. Übersetzung aus dem Russischen, Walter Phillip. La. 8vo, pp. 292. Illustrated. Berlin, 1953: VEB Verlag Technik. (Price 43*s.*).

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